WASHINGTON STATE DEPARTMENT OF ECOLOGY

# Technical Report on Groundwater Storage Alternatives for Yakima River Basin Storage Assessment

In support of the Yakima River Basin Water Storage Feasibility Study Draft Planning Report/Environmental Impact Statement

Ecology Publication Number 08-12-001

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Washington State Department of Ecology

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# EXECUTIVE SUMMARY

The U.S. Bureau of Reclamation (Reclamation) and the Washington State Department of Ecology (Ecology) are preparing a Draft Planning Report/Environmental Impact Statement (Draft PR/EIS) to evaluate the viability of storage alternatives in the Yakima River Basin, and to determine the extent to which these alternatives can provide additional water storage. The current water supply and storage capacity within the Yakima River Basin does not meet the water supply demands in all years and affects the Yakima River Basin's economy, which is agriculture-based. Water resources are also vital to the basin's aquatic resources—specifically those resources supporting anadromous fish. Reclamation and Ecology seek to identify a means of increasing water supplies available for purposes of improving anadromous fish habitat and meeting irrigation and municipal needs. This report supports this effort and evaluates the feasibility of groundwater storage alternatives as part of the state's alternatives analysis.

The groundwater storage alternatives include surface recharge with passive recovery, municipal aquifer storage and recovery, and direct injection with passive recovery. These alternatives include placing water in the aquifer system and storing it to realize benefits in the form of increased streamflow from increased groundwater discharge, recovery of the stored water for out-of-stream uses, and/or replenishing depleted groundwater storage. The groundwater storage alternatives are conjunctive use tools in which the use of surface water and groundwater can be coordinated to minimize impacts to the hydrologic system and provide environmental benefits.

**Surface Recharge**

Surface recharge with passive recovery involves diverting and infiltrating surface water into a recharge basin during periods of high streamflow and allowing it to naturally discharge back to a stream. The objectives for applying the surface recharge (passive recovery) method to locations in the Yakima River Basin include:

1. Offset impacts of current irrigation surface water withdrawals on streamflows

2. Improve reliability for certain agricultural water demands during water short years by increasing Total Water Supply Available (TWSA)

3. Provide capability for surface application and storage of reclaimed water

The volume and timing of water diverted to an infiltration pond and the subsequent timing and volume of return flow to the stream were evaluated using two approaches: 1) target return flow profile; and 2) excess surface storage. The target return flow profile approach identified a desired condition for groundwater return flows, and examined the amount of infiltration and total area of infiltration ponds required to achieve the target infiltration profile. The excess surface storage approach evaluated the amount of infiltration and total area required when the availability of water for infiltration is constrained by the historical storage volumes in reservoirs in excess of entitlements and flow requirements.

The results of the first approach, the target return flow approach, indicate that to "normalize" groundwater return flows to a level that would be consistent from year-to-year requires delivery of significant amounts of water during July and August. While there will be some flexibility in optimizing the system by choosing areas with differing stream depletion factors (SDF) values, it is not likely that surface recharge alone will offset the effects of drought conditions on streamflows or TWSA for downstream water right holders.

The excess surface storage approach used the historical monthly availability of reservoir storage for the period from 1978 to 2000 to determine which months there was "excess" reservoir storage that could be diverted into infiltration ponds. It was assumed that between 10,000 and 20,000 acre-feet (AF) of water could be released when excess storage exceeded 25,000 AF. In many months, there is no excess storage, and no infiltration is assumed during that month. The annual delivery volume, on average, is expected to be 33,000 AF. The expected delivery volume in drought years is expected to range from 10,000 to 20,000 AF for the year.

The surface recharge analysis used the SDF view program, version 2.0.11 to estimate the monthly return flow (or accretion) to the river based on monthly infiltration volumes and a range of stream depletion factors (SDF). The stream depletion factor is a function of the distance between the site and a stream, the transmissivity of the aquifer, and the specific yield of the aquifer. The SDF program generates a stream depletion function that shows how the return flow peaks and decays over time. Smaller SDF values result in a more rapid peak and decay in return flow which means that more of the infiltrated volume of water reaches the stream within a few months of the infiltration event. SDF values of 30, 40, 50, and 60 days were used in the analysis because they would result in larger volumes of same-season return flow.

The streamflow improvements from surface recharge as a percent of the historical monthly flows at Umtanum gauge were estimated. In terms of streamflow improvements, the return flow estimates suggest that infiltration of 10,000 AF/month during months when there is excess TWSA will result in average and maximum August streamflow improvements of 2.3 to 5.2 percent at Umtanum gauge. The average streamflow improvement in August is expected to range from 4,903 to 5,244 AF (80 to 85 cfs), depending on the SDF value at the site. Streamflow improvements of up to 12 and 15 percent are predicted for drought years (1993) in October. This represents approximately 4,900 to 6,200 AF (80 to 100 cfs) of return flow from surface recharge. If 20,000 AF/month were infiltrated during months when there is excess TWSA, August streamflow improvements of 4.7 to 9.6 percent are predicted. This represents approximately 10,100 to 14,400 AF (170 to 240 cfs) of return flow from surface recharge. Under a 20,000 AF scenario, streamflow improvements of 6 to 28 percent are predicted for drought years (1993) in September and October, depending on the relative proportion of areas with a SDF value of 30 or 60. This represents approximately 5,700 to 11,000 AF (95 to 185 cfs) of return flow from surface recharge.

There were not enough data available to identify specific sites and SDF properties for surface recharge. However, a screening of potential areas was conducted based on surficial geology, land cover, estimated aquifer properties, and distance buffers around the Yakima River and main tributaries. The distance buffers are based on conditions within each basin that would result in a SDF of 30, 40, 50, or 60. Site identification will require a site investigation, including drilling and aquifer testing to obtain estimates of hydrogeologic properties.

For the Yakima River Basin, total land area could range between 166 and 500 acres for similar infiltration capacities, with an expected area of about 300 acres. Total construction costs could range from $54M to $164M, with an expected cost of $98M. Assuming that surface recharge would return an average of about 33,000 AF annually from groundwater storage, the annual cost per AF for groundwater storage is estimated to be in the range of $1,646 to $4,958 per AF, with an expected value of $2,975 per AF. Annual O&M costs are estimated to be about $2.1M per year.

**Injection Recharge**

Injection recharge is a method that injects water via wells into a deep subsurface geologic formation. The injected water may or may not be recovered depending on the objective of the recharge. Municipal ASR is the term used when the stored groundwater is actively recovered for potable uses. When the storage is allowed to discharge naturally, it is called injection with passive recovery.

The objectives of direct injection within the Yakima Basin are to:

1. Replace direct surface water diversions and groundwater withdrawals that have direct or seasonally significant impacts on streamflows

2. Replace groundwater withdrawals that may otherwise have a longer-term impact on streamflows

3. Provide for future water demands with minimal or no impact to streamflows

4. Mitigate impacts from future water demand by augmenting streamflow

The objectives for applying the direct injection with passive recovery method to locations in the Yakima River Basin include:

1. Offset current irrigation surface water withdrawals to improve streamflows and overall water supply reliability

2. Mitigation offset for future water municipal rights

3. Maintain and/or restore depleted aquifer storage to extend the sustainable yield of the aquifer

4. Increase groundwater storage that may be used during emergency drought conditions

5. Create local salmonid refugia

Identified candidates that may benefit from direct injection include the cities of Yakima (Ahtanum Valley), Ellensburg (Kittitas Valley), Kennewick (Lower Valley), the Blackrock-Moxee Valley and in the Lower Yakima Valley immediately downstream of Union Gap. The analysis focused on the Ahtanum, Kittitas, and Blackrock-Moxee areas because the sites are upstream of the Parker gauge where the TWSA is established.

A three-dimensional groundwater flow model was used for the Ahtanum-Moxee Sub-basin in the Yakima Valley to evaluate the potential for using Aquifer Storage and Recovery (ASR) as a groundwater management option. The goal of the model was to estimate the quantity of recharged water to three injection wells that would (a) return to the Yakima River, (b) discharge at other hydrologic sinks, and (c) remain in the subsurface in the form of increased groundwater storage. The focus of the model was on seepage return flows to the Yakima River that result from direct injection to the deeper portions of the Ellensburg Formation. An analysis of active recovery was based on the increased aquifer storage. The model results were used to evaluate the Ahtanum, Kittitas, and Blackrock-Moxee sites.

Direct injection was simulated in the model to estimate the quantity of recharged water that discharged from the aquifer system to the Yakima River (thereby increasing flows) and to determine how much water remained in storage. The direct injection simulation included recharging water into the three wells for six months (i.e., October to March) at a constant rate of 2,000 gpm (4.46 cfs) each. Recharge ceased for the subsequent six months, and the cycle was repeated for nine years. The numerical computer simulation considered recharge at three wells, each at a rate of 2,000 gpm (total of 6,000 gpm) for six months (e.g., October through March) for an annual recharged volume of 4,800 acre feet. Application of the numerical computer simulation to specific sites extrapolates the simulation results to four wells, each at a rate of 2,000 gpm. The hydraulic responses are assumed to be linear, and are increased by a factor of 4:3 (1.33). Therefore, the total rate at each site is 8,000 gpm over six months to result in a recharge volume of 6,400 acre feet at each site.

The benefits of direct injection may be realized in several ways. Four end member scenarios are described, followed by one hybrid scenario:

1. Replacement of Current Surface Water Diversions: Replacing current municipal summer surface water diversions with ASR would result in a direct increase to streamflow during the 6-months from April to September. Recovery of 6,000 AF of ASR would improve TWSA initially by 6,000 AF. Yakima River flows would be additionally by augmented by between 0 to 1.2 cfs of seepage of injected water from the aquifer.

2. Pump and Dump: Direct discharge of ASR water to the Yakima River (i.e. “pump & dump”) would increase Yakima River flows by 6,000 AF in the 6 months from April to September. This would also provide additional water quality benefits of clean clear cold water to the Yakima River, which is water quality impaired with respect to turbidity, temperature, and other parameters.

3. Satisfying Future Demand: Satisfying future demands with ASR would reduce demand pressure on the Yakima River by 6,000 AF. It would also increase

Yakima River streamflows over current levels by the nonconsumptive portion withdrawal (i.e. return flows from wastewater treatment would essentially put a portion of the ASR storage directly back to the river). This would be on the order of 2,700 AF if used for city of Yakima municipal water supply (e.g., 45 percent nonconsumptive use from April through September).

4. Passive Recovery: Allowing injected water to seep back to the Yakima River would increase TWSA by a maximum of 50 percent of the annual injection rate. This would augment Yakima River flows by approximately 3,200 AF, assuming an annual inject rate of 6,400 AF. Only 50 percent of the injected volume contributes to TWSA because seepage is constant year-round, including 50 percent of the seepage volume during the irrigation season (April through September) and 50 percent of the seepage volume during the irrigation off-season (October through March).

5. Intermittent Active Recovery: One approach to using groundwater storage is to only access or use stored groundwater during water short years. Water stored during non water short years may be saved or banked for later use. Intermittent use would maximize the quantity of stored water for water short years because the recoverable amount of water is more than just what was stored in the most recent recharge season, and seepage rates to the Yakima River will be higher than if the injected water were recovered annually. For instance, direct injection during winter months for 10 years at a rate of 8,000 gpm (four wells at 2,000 gpm each) results in an increased aquifer storage of approximately 38,000 acre feet and an estimated seepage rate of 5.2 cfs to the Yakima River (which presents a recharge scenario at rate of 6,000 gpm through three wells). Recovery of the additional stored water may require additional recovery wells.

The costs associated with a direct injection program include infrastructure associated with obtaining recharge water (e.g., surface water treatment facilities or river bank filtration wells), transmission pipelines, injection wells, and additional costs (permitting, operations and maintenance, land acquisitions for facilities). The total cost for the direct injection sites with active recovery ranges from $18.2M to $26M for 6,000 AF of streamflow benefit from each site during April to September.

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# ACRONYMS/ABBREVIATIONS

| | |
|---|---|
| AF | acre feet |
| ASR | aquifer storage and recovery |
| CAP | Central Arizona Project |
| CRBG | Columbia River Basalt Group |
| cfs | cubic feet per second |
| DBP | disinfection by product |
| Decree | Consent Decree |
| Draft PR | Draft Planning Report |
| Ecology | Washington State Department of Ecology |
| EES | Economic and Engineering Services |
| GIS | Geographic Information System |
| HAA | haloacetic acid |
| gpm | gallons per minute |
| In/yr | inches per year |
| $mi^2$ | square mile |
| mgd | million gallons per day |
| mgl | milligrams per Liter |
| msl | mean sea level |
| NWIS | National Water Information System |
| O&M | operation and maintenance |
| OFM | Office of Financial Management |
| PRMS | Precipitation Runoff Modeling System |
| RBF | river bank filtration |
| SDF | stream depletion factor |
| SDA | Safe Drinking Water Act |
| SOAC | Systems Operating Advisory Committee |
| THM | trihalomethanes |
| TSS | total suspended solids |
| TWSA | total water supply available |
| USGS | U.S. Geological Survey |
| WAC | Washington Administrative Code |
| WY | water year |
| WSDOH | Washington State Department of Health |
| YRBWEP | Yakima River Basin Water Enhancement Project |

# 1.0 INTRODUCTION

## 1.1 PURPOSE AND OBJECTIVE

The U.S. Bureau of Reclamation (Reclamation) and the Washington State Department of Ecology (Ecology) are preparing a Draft Planning Report/Environmental Impact Statement (Draft PR/EIS) to evaluate the viability of storage alternatives in the Yakima River Basin, and to determine the extent to which these alternatives can provide additional water storage. The current water supply and storage capacity within the Yakima River Basin does not meet the water supply demands in all years and affects the Yakima River Basin's economy, which is agriculture-based. Water resources are also vital to the basin's aquatic resources—specifically those resources supporting anadromous fish. Reclamation and Ecology seek to identify a means of increasing water supplies available for purposes of improving anadromous fish habitat and meeting irrigation and municipal needs. This report supports this effort and evaluates the feasibility of groundwater storage alternatives as part of the state's alternatives analysis.

The groundwater storage alternatives include municipal aquifer storage and recovery, direct injection with passive recovery, and surface recharge with passive recovery. These alternatives include placing water in the aquifer system and storing it to realize benefits in the form of increased streamflow from increased groundwater discharge, recovery of the stored water for out-of-stream uses, and/or replenishing depleted groundwater storage. The groundwater storage alternatives are conjunctive use tools in which the use of surface water and groundwater can be coordinated to minimize impacts to the hydrologic system and provide environmental benefits.

Aquifer Storage and Recovery (ASR) is a specific application of artificial recharge in which water is recharged to an aquifer and stored for later recovery and use. Typically, ASR involves diverting water during times of higher availability, usually surface water during the winter and spring runoff season, and recharging it into aquifers that act as storage reservoirs. The stored water is then withdrawn during times of higher demand and lower availability. Conventional ASR projects operate on an annual cycle and withdraw during dry summer seasons. However, longer multiyear cycles may also be considered, such as recharging every year and only withdrawing during drought years.

Direct injection can also be used to store water in the aquifer with passive recovery. Potable water would still be injected into an aquifer during periods of excess capacity but the water would become part of the natural groundwater system and remain in the aquifer and flow to its natural discharge areas (i.e., streams or springs). The water would be passively recovered when it reaches the stream and is available for instream or out-of-stream uses.

Surface recharge with passive recovery involves diverting and infiltrating surface water into a recharge basin during periods of high streamflow and allowing it to discharge naturally back to a stream. The recharge basins are located so that the timing of return flow to a stream corresponds to periods of low flow. The water would be available for instream or out-of-stream uses when it reaches the stream.

## 1.2 BACKGROUND

The Yakima Basin is located in eastern Washington (Figure 1-1). The following description of the Yakima Basin is from the Bureau of Reclamation's Interim Comprehensive Basin Operating Plan for the Yakima project (Reclamation, 2002). Elevations range from 8,184 feet in the Cascades to 340 feet at the mouth of the Yakima River. The Yakima River flows for about 215 miles. Its major tributaries include the Naches, Kachess, Cle Elum, and Teanaway Rivers in the upper basin (above Yakima), and Toppenish and Satus Creeks in the lower basin. Timber, cattle, fish and wildlife habitat, and recreation are the major uses of the northern and western areas of the basin, while irrigated agriculture is the main economy of the lower basin. Climate ranges from alpine to arid, with precipitation varying from 140 inches annually in the Cascades to less than 10 inches in the Kennewick area (Reclamation, 2002).

The Yakima Project was authorized by Congress in 1905 to increase the storage capacity within the basin. Development of the Yakima Project progressed with the construction of Bumping Dam (1910), Kachess Dam (1912), Clear Creek Dam (1914), Keechelus Dam (1917), Tieton Dam (Rimrock Lake, 1925), and Cle Elum Dam (1933). These six federal reservoirs have a total storage capacity of 1,070,000 acre-feet and provide the water supply necessary to help meet the irrigation and instream flow needs by storing and regulating a portion of the flow of the Yakima River and its tributaries. Other principal features of the Yakima Project include several diversion dams, two hydroelectric generating plants, and numerous canals, laterals, and pumping plants (Reclamation, 2002).

During years of low runoff, disputes began over water use in the basin. In 1945, the District Court of Eastern Washington issued the 1945 Consent Decree (Decree), which established the rules under which the U.S. Bureau of Reclamation should operate the Yakima Project. The Decree determined the quantities of water to which all project users are entitled, and defines a prioritization for water-short years. Users were divided into two classes, nonproratable (those with the most senior rights) and proratable. Nonproratable users are served first from the total water supply available (TWSA) and proratable users share equally in the balance of available supply (Reclamation, 2002).

Since 1945, the courts have issued numerous other decisions in the Yakima Basin Adjudication related to protection of fish resources, the rights of the Yakama Nation, return flows, groundwater, abandonment of claims, and flood water use.

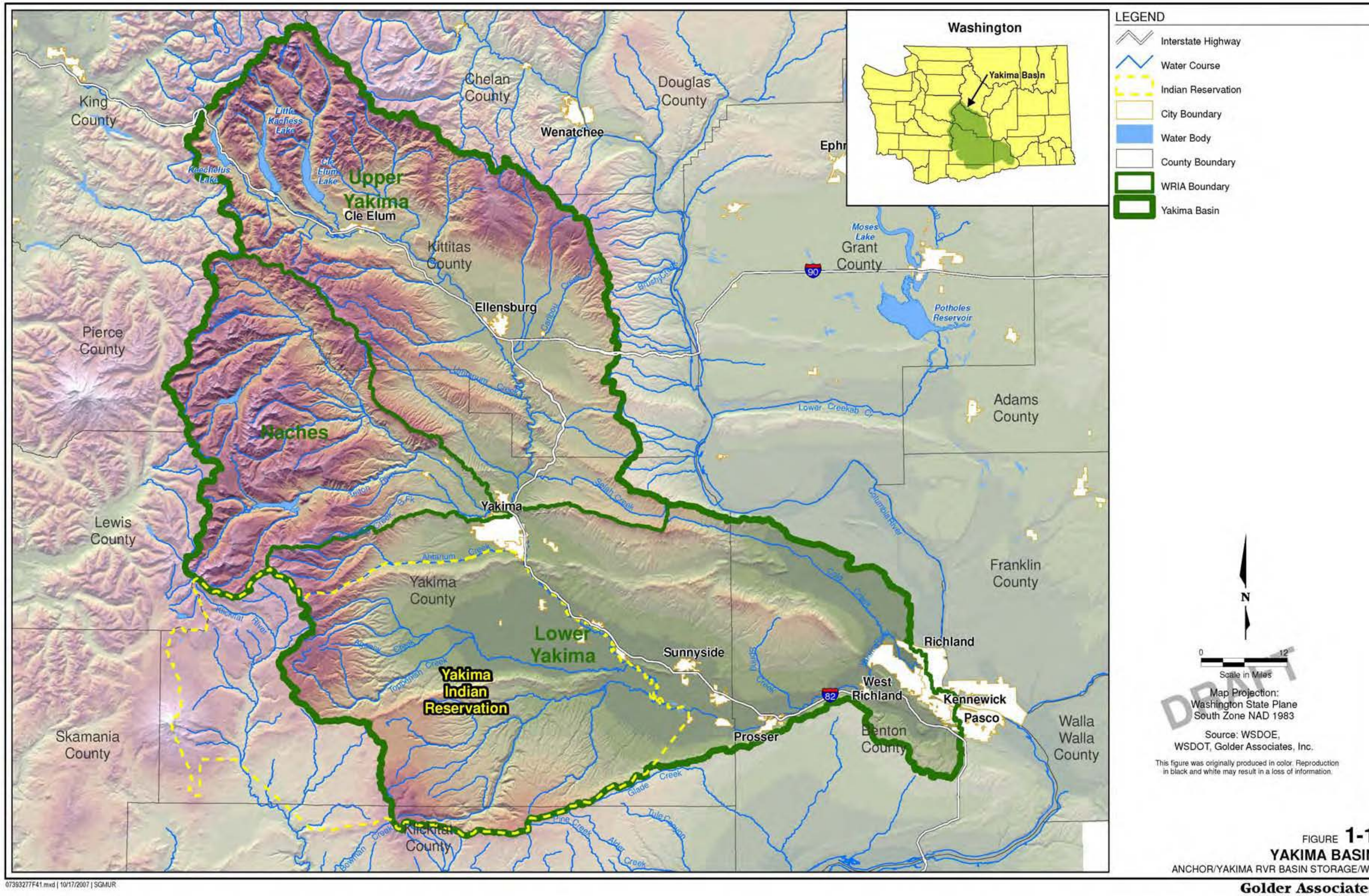
Washington
Yakima Basin
LEGEND
Interstate Highway
Water Course
Indian Reservation
City Boundary
Water Body
County Boundary
WRIA Boundary
Yakima Basin
King County
Chelan County
Douglas County
Wenatchee
Upper Yakima
Cle Elum
Kittitas County
Grant County
Ellensburg
Pierce County
Adams County
Naches
Lewis County
Yakima
Franklin County
Yakima County
Lower Yakima
Sunnyside
Richland
West Richland
Kennewick
Pasco
Yakima Indian Reservation
Prosser
Benton County
Walla Walla County
Skamania County
Klickitat County
Scale in Miles
Map Projection: Washington State Plane South Zone NAD 1983
Source: WSDOE, WSDOT, Golder Associates, Inc.
This figure was originally produced in color. Reproduction in black and white may result in a loss of information.
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FIGURE 1-1
YAKIMA BASIN
ANCHOR/YAKIMA RVR BASIN STORAGE/WA
Golder Associates

## 1.3 DOCUMENT ORGANIZATION

This technical report is divided into the following sections:

- Section 1.0: Introduction
- Section 2.0: Description of the Groundwater Storage Alternatives
- Section 3.0: Background
- Section 4.0: Surface Recharge with Passive Recovery
- Section 5.0: Direct Injection
- Section 6.0: References

Section 2 describes the groundwater storage alternatives and is related to the project description in the Draft PR/EIS. Section 3 provides background information on the project areas, water demands and water management within the Yakima River Basin, and hydrogeologic characteristics of the basin. Section 4 contains the methods, analysis, and results of the surface recharge alternative. Section 5 contains the methods, analysis, and results of the direct injection alternative. The information in Sections 4 and 5 can be used to describe the affected environment and can be used to identify potential impacts from groundwater storage for the Draft PR/EIS.

# 2.0 DESCRIPTION OF GROUNDWATER STORAGE ALTERNATIVES

The groundwater storage alternative includes using the natural storage capacity of geological formations in both the confined (i.e., deep) and unconfined (i.e., water table) portions of the aquifer system. The approach includes recharging water (placing water in) the aquifer system and storing it to realize benefits in the form of increased streamflow from increased groundwater discharge, recovery of the stored water for out-of-stream uses, and/or replenishing depleted groundwater storage.

Aquifers provide a natural storage reservoir that can be used to store the water available under an existing water right. Water available during off-peak times can be stored in an aquifer and recovered to supply peak demands. Aquifer storage can also augment streamflows during peak demand periods through increased groundwater discharge of the water stored during off-peak periods. Thus, groundwater storage can provide a more reliable water source or increase stream baseflow during critical times. The geological formations targeted for groundwater storage include the following:

- Shallow alluvium and unconsolidated sediments
- Basin fill sedimentary rock (e.g., Ellensburg Formation)
- Basalts

Groundwater storage is achieved by recharging water to the deep and shallow portions of the aquifer system (i.e., confined and unconfined). There are two distinct methods of recharge:

- Direct Injection. This method injects water via wells and targets deeper confined aquifers.
- Surface Infiltration. This method distributes water at the ground surface, which then infiltrates to a shallow, unconfined aquifer.

The two recharge methods are sufficiently different in terms of technology, impacts, and costs; therefore, they are considered as separate groundwater storage alternatives in the EIS.

The source water is expected to be surface water from either the Yakima River or one of its tributaries. New or existing infrastructure (canals or pipelines) would be used to convey this water to the recharge site. The availability of water will be a function of seasonal timing and location within the Yakima River Basin.

## 2.1 INJECTION RECHARGE

Injection recharge is a method that injects water via wells into a deep subsurface geologic formation. The injected water may or may not be recovered, depending on the objective of the recharge. Municipal ASR is the term used when the stored groundwater is actively recovered for potable uses. When the storage is allowed to discharge naturally, it is called injection with passive recovery.

### 2.1.1 Municipal Aquifer Storage and Recovery

Municipal ASR systems inject potable water via wells into aquifers during periods of excess capacity and withdraw the water for municipal supply during periods of peak demand or limited supply. In Washington State, ASR systems are regulated under Washington Administrative Code (WAC) 173-157. Figure 2-1 shows a typical configuration of an ASR system. The source water must be of high quality (i.e., near-potable quality) for operational purposes (i.e., to prevent well clogging by sediment and biological growth) to meet state regulations that protect groundwater quality, and to better ensure potable quality when recovered. Water of such quality may be obtained from conventional drinking water treatment plants, or from groundwater wells (e.g., shallow alluvial wells in close hydraulic continuity with surface water – this configuration is also referred to as river bank filtration [RBF]).

The water is injected directly into an aquifer (usually confined), and the stored water is actively recovered for potable supply using the same or other wells. ASR systems require recharge/recovery wells and conveyance infrastructure to transport the water from the source to the recharge well and from the recovery well to the municipal supply. ASR systems are an established and well-regulated management technique for water systems with appropriate source water and infrastructure configurations.

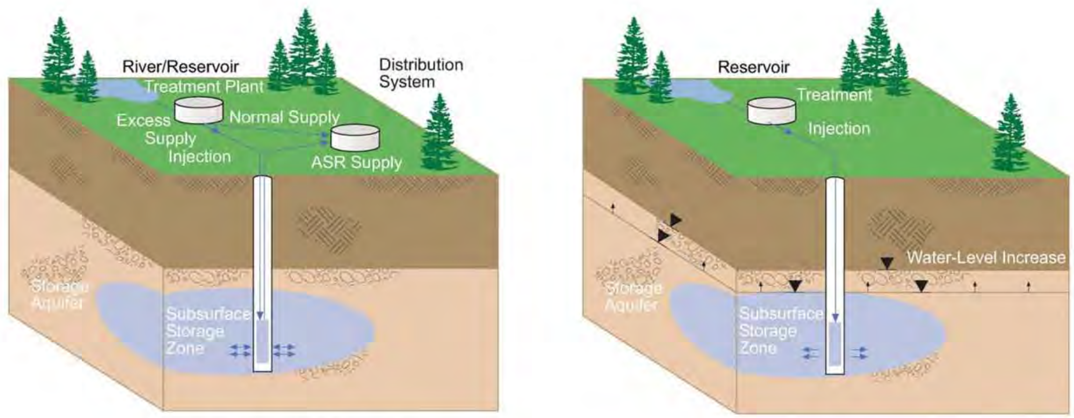
The hydrogeology of an area is an important factor in locating recharge sites. The aquifer must have suitable hydraulic properties and, in some cases, favorable hydraulic boundaries to ensure that the stored water can be efficiently recovered and not lost to streams or captured by other water users. This is why the ASR alternative in the Yakima River Basin targets deeper aquifers in the Ellensburg Formation or basalts. Water that is not actively recovered may remain in the aquifer or seep back to streams. This can improve groundwater levels locally and may improve baseflow to surface waters in hydraulic connection with deeper geologic formations. The objectives for applying the municipal ASR method include the following:

1. Offset current and future municipal surface water withdrawals to seasonally improve streamflows and overall water supply efficiency

2. Improve reliability of peak and long-term water supply

3. Recover deeper groundwater levels and baseflow discharge over the long term

4. Provide the potential capability for storage of reclaimed water




**Municipal Aquifer Storage and Recovery (ASR)**

**Injection with No Recovery**

FIGURE **2-1**
**INJECTION RECHARGE**
ANCHOR/YAKIMA RVR BASIN STORAGE/WA

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**Golder Associates**

The first objective, offsetting municipal surface water withdrawals, would be achieved by diverting water under a municipal water right during off-peak demand periods and injecting it into an aquifer. The water would then be actively recovered during peak demand periods and thereby reduce the surface water demand during that period. Peak municipal demands are generally during the summer months when streamflows are lower, so this method would improve surface water supply by decreasing the impacts to streams during the summer. Storing water in aquifers would also reduce evaporation losses compared to losses that would be expected if the water were stored in a surface reservoir.

The second objective, improving the reliability of the peak and long-term supply, would be achieved in the same way as the first objective; however, the recovery of the water would be postponed until the municipal demand exceeds the current supply. The long-term storage and recovery of the water will also enable the municipality to meet future peak demands.

The third objective, improving groundwater conditions over the long-term, would be achieved based on the long-term annual ratio between injection storage and recovery. Water that is left in the aquifer and not actively recovered would, over the long term, become part of the natural groundwater system.

The fourth objective, storing reclaimed water, would be achieved by injecting reclaimed water (treated to the necessary standards) into an aquifer and allowing direct recovery of the water for future municipal use. This approach would make efficient use of the municipal water use under an existing water right because it would put the water into a reclaim and reuse cycle that would offset a portion of future municipal demands from the stream.

#### *2.1.1.1 General Requirements*

The feasibility of ASR for municipal purposes depends on water quality, infrastructure, costs, permitting, hydrogeology, a suitable recharge water source, and customer acceptance (aesthetic parameters associated with water quality). A summary of these considerations is presented below.

**Water Quality:** Water quality concerns for an ASR project relate to human health and operational considerations. An ASR project used to supply municipal drinking water must meet federal (Safe Drinking Water Act [SDWA]) and Washington State Department of Health [WSDOH], WAC 246-290) drinking water standards. Any reactions between the recharged water and the native groundwater and aquifer mass must result in concentrations of regulated parameters that meet drinking water standards, if used for drinking water purposes.

Operational water quality concerns include biological growth, mineral precipitation and dissolution, and corrosion of the well screen. Bacterial growth and mineral precipitation (which is often catalyzed by bacteria) can cause clogging of the well screen. Problems related to mineral dissolution are more likely associated with meeting drinking water standards (e.g., dissolution of sulfide minerals may release heavy metals). In extreme, but unlikely, cases, dissolution of minerals may cause aquifer stability formation problems around the well screen.

**Infrastructure:** Suitable infrastructure for ASR must be available or constructed, possibly including facilities for the treatment of surface water used for direct injection, a distribution system from the source of recharge water (e.g., streams) to recharge sites, and wells suitable for ASR (i.e., recharge and recovery wells). Treatment of surface water is needed for two reasons: 1) to ensure low total suspended sediments (TSS) that may otherwise clog an ASR well, and 2) to reduce pathogens that may be present in surface water for the protection of human health.

The cost of obtaining water of the desired quality for direct injection can be reduced relative to surface water treatment plants by using river bank filtration (RBF) methods. RBF methods include withdrawing groundwater from wells in close hydraulic continuity with surface water. This method uses the natural filtration capacity of sediments to filter TSS and pathogens that may be present.

**Costs:** The cost of ASR must be favorable in comparison to other water management strategies. A higher cost for ASR relative to other water management or storage strategies may be acceptable if there is a net environmental benefit or other enhancement. Generally, the costs of an ASR program benefit from scales of economy (i.e., the larger the project, the lower the unit cost of providing the water). Under certain conditions, cost is a minimal concern if no other feasible alternative is available (e.g., water rights are not available because of the seasonal impacts of water use on stream flows or limited groundwater availability).

**Permitting:** ASR is a water resource management tool that is explicitly endorsed by Washington State. Numerous regulations must be complied with and permits obtained for an ASR project. These regulations are intended to ensure the protection of human and environmental health. A valid ASR project should be able to adequately comply with these regulations and permitting requirements without significant effort. The following is a list of the primary applicable regulations:

- Water Rights (RCW 90.03 and 90.44)
- ASR (WAC 173-157)
- Well Construction (WAC 173-160)
- Water Quality (WAC 173-200)
- Underground Injection Control Program (WAC 173-218)
- Washington State Department of Health (WAC 246-290)

The water recovered in an ASR program for potable use has to meet drinking water standards. Water rights also have to be available. Water may be more available for ASR permits than for conventional water right permits that involve year-round uses because the diversion of water for storage in an ASR program typically occurs during the off-season or rainy season.

**Hydrogeology:** A favorable hydrogeological setting for ASR is one that retains the recharged water for later recovery (e.g., a well-confined system that limits the loss of water from the system), and an aquifer that is sufficiently permeable to avoid excessive build-up of head at the injection well.

**Recharge Water Source:** A source of high-quality recharge water is required. The water must effectively meet drinking water standards in order to meet the regulatory standards of WAC 173-200 (Protection of Groundwater Quality). It should also be chemically compatible with the native groundwater and aquifer mass; otherwise, the aquifer may need conditioning by multiple flushing cycles.

**Customer Acceptance:** The water that is recovered and furnished to drinking water customers has to be acceptable from aesthetic standpoints (e.g., taste and odor). Customers are usually accustomed to a particular "flavor" of water. Changes of any kind typically elicit questions of concern from customers. Although these changes may be of no health concern (e.g., temperature) or of variable health concern (e.g., increased calcium concentrations although not regulated for drinking water may contribute to gall stone formation or mitigate osteoporosis), such changes must be satisfactorily addressed in order to ensure public acceptance.

### 2.1.2 Injection with Passive Recovery

Direct injection can also be used to store water in the aquifer with passive recovery (Figure 2-1). Potable water would still be injected into an aquifer during periods of excess capacity but the water would become part of the natural groundwater system and flow to its natural discharge areas (i.e., streams or springs). The water would be passively recovered when it reaches the stream and is available for instream or out-of-stream uses. Injection into a deep aquifer results in a longer lag time between injection and when the water reaches its natural discharge areas (i.e., streams or springs). This interannual retention time provides a more constant discharge of recharged water to streams and other discharge areas. Injection to shallower portions of the aquifer system will provide shorter lag times between the time of recharge and the time of peak return flows.

Direct injection with passive recovery requires a high-quality water source (as described in Section 2.1.1.1 for municipal ASR), recharge wells, and conveyance infrastructure to transport the water from the source to the well. The system would still be subject to WAC 173-157 because water is being injected into an aquifer.

The siting of this type of injection system is different than a typical ASR system. Areas would be targeted that have hydraulic continuity between the aquifer and natural discharge areas that would benefit from increased baseflow. Areas where groundwater has been depleted or mined through heavy use could also be targeted to restore water levels. For both purposes, the benefits would be realized over a long period of time and distributed over a relatively large area.

The objectives for applying the direct injection with passive recovery method to locations in the Yakima River Basin include the following:

1. Offset current irrigation surface water withdrawals to improve streamflows and overall water supply reliability

2. Mitigation offset for future municipal water rights

3. Maintain or restore depleted aquifer storage to extend the sustainable yield of the aquifer

4. Increase groundwater storage that may be used during emergency drought conditions

5. Create local salmonid refugia

The first objective, offsetting current irrigation surface water withdrawals, is targeted for areas that have experienced, or may experience, significant groundwater level declines due to a large groundwater demand. If an aquifer is in hydraulic continuity with a stream, then it is possible that the groundwater level decline may be currently impacting surface discharges, such as streams or springs. Injection recharge could reduce current impacts of groundwater use on the stream over the long term. Maintaining or raising groundwater levels could reduce pumping costs and extend the life of existing wells.

The second objective, mitigating future water rights, is intended to provide an option for one or more municipalities to inject water into an aquifer to mitigate for the impacts of a future surface or groundwater withdrawal needed to support growth. This form of mitigation would require a system designed to recharge the same body of water (aquifer) from which the withdrawal is occurring, and would need to raise or maintain groundwater levels so that other groundwater users are not impaired. The source water would still be obtained during times of off-peak demand. It may be appropriate for groups of two or more entities requiring water to jointly develop the mitigation near their proposed withdrawals.

The third objective, restoring depleted aquifer storage to extend the sustainable yield of the aquifer, is intended to replenish groundwater storage where it has been depleted by historical pumping of groundwater. In such areas, groundwater withdrawals are greater than natural recharge rates and groundwater levels have dropped by up to several hundred feet. This has resulted in groundwater users having to deepen wells and pay greater pumping costs as greater head lifts are needed. Increasing the recharge of the aquifer may slow or arrest the rate of decrease of groundwater levels, and possibly replenish depleted groundwater storage.

The fourth objective, increasing groundwater storage that may be used during emergency drought conditions, is similar to the third objective. Temporary emergency drought wells are often permitted during drought years. However, issuance of such permits still requires nonimpairment on other groundwater users. Therefore, increasing the available groundwater storage will provide additional storage to supply temporary drought permits for groundwater withdrawal.

The fifth objective, creating local salmonid refugia, is intended to facilitate salmonid migration and improve spawning grounds. Cold groundwater seeps to streams often provide refugia for migrating salmon and are the locations of spawning. Groundwater seeps are often associated with geological structures, such as faults or fold structures. Recharge of cold surface water during the winter at certain geologic structures may increase the flux of cold water to streams at existing areas of groundwater discharge and salmonid refugia.

#### *2.1.2.1 General Requirements*

The general requirements for injection with passive recovery are the same as those required for municipal ASR with the exception of the hydrogeology. The general requirements for municipal ASR are discussed in Section 2.1.1.1. The hydrogeology requirements for injection with passive recovery are different from municipal ASR because the objective is to have the injected water naturally discharge back to a stream over time. This requires a hydraulic connection between the hydrogeologic unit targeted for injection and a stream. The aquifer still needs to be moderately to highly permeable to accept the recharge water within excessive build-up of head. The native groundwater and aquifer mass should also be chemically compatible with the recharge water to prevent changes in the stored water quality or precipitation of minerals that could clog the well or aquifer.

## 2.2 SURFACE RECHARGE WITH PASSIVE RECOVERY

Surface recharge with passive recovery involves diverting and infiltrating surface water into a recharge basin during periods of high streamflow and allowing it to discharge naturally back to a stream (Figure 2-2). The natural discharge back to the stream is termed passive recovery because the water is available for instream and out-of-stream uses when it reaches the stream. The infiltration sites are located so that the timing of return flow to a stream corresponds to periods of low flow. The source of the infiltration water would be a direct surface diversion from a river or irrigation canal, or suitably high-quality reclaimed water. The infiltration system recharges water before lower streamflow conditions occur. Pumping or other infrastructure may be required to move water from the source to the infiltration basin.

Using surface recharge to augment streamflows requires a good understanding of stream-aquifer interaction to effectively manipulate the timing of return flows to benefit the stream. The effectiveness of surface recharge is dependent on the properties of the aquifer system (e.g., storativity and transmissivity), and is targeted for shallow alluvium and unconsolidated sediments in the Yakima River Basin.

The objectives for applying the surface recharge (passive recovery) method to locations in the Yakima River Basin include the following:

1. Offset impacts of current irrigation surface water withdrawals on streamflows
2. Improve reliability for certain agricultural water demands during water short years by increasing TWSA
3. Provide capability for surface application and storage of reclaimed water

The first objective, offsetting current irrigation surface water withdrawals, would be achieved by increasing the magnitude of return flows during the irrigation season.

The second objective, improving reliability for certain agricultural water demands, would also be achieved by increasing the magnitude of return flows during the irrigation season. Higher streamflows could improve the reliability of supply to junior water right holders because irrigation deliveries are managed by streamflow levels at various control points along the Yakima River. In addition, surface recharge could return to irrigation canals.

The third objective, storing reclaimed water, is a longer term objective that would infiltrate municipal reclaimed water if and when suitable infrastructure is developed to handle a reclaimed water system.

### 2.2.1 General Requirements

The feasibility of surface infiltration depends on infrastructure, costs, permitting, hydrogeology, a suitable recharge water source, and the timing of return flows to the river.

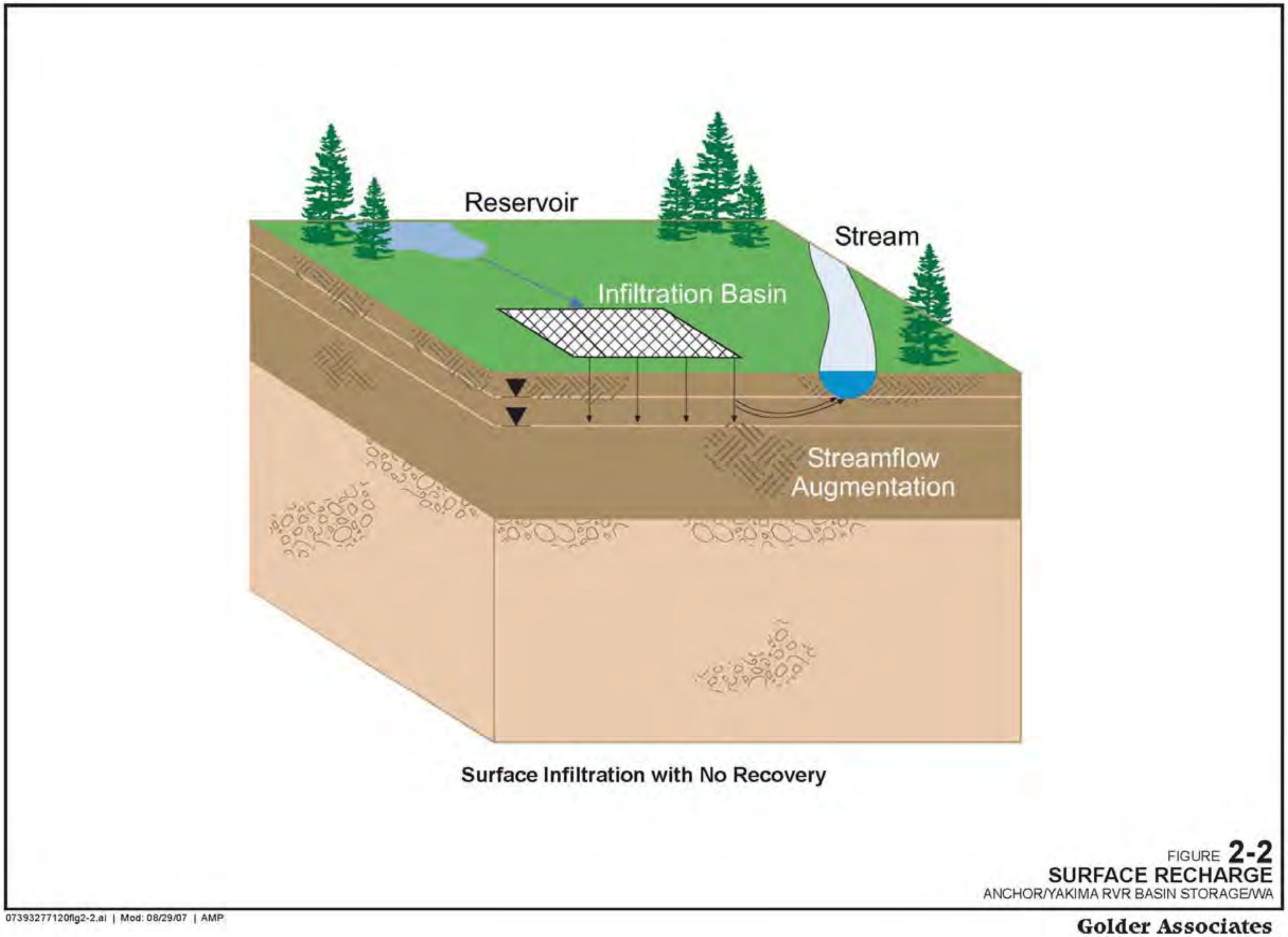
**Infrastructure:** Suitable infrastructure for surface infiltration must be available, including a distribution system from the source of recharge water to the infiltration facility sites.

**Costs:** The cost of surface infiltration must be favorable in comparison to other water management strategies. A higher cost for surface infiltration relative to other water management of storage strategies may be acceptable if there is a net environmental benefit or other enhancement. The costs for surface infiltration include infrastructure and leasing or purchase costs for the land needed to site infiltration facilities. Close proximity to sources of water from infrastructure such as canals and ditches will reduce infrastructure costs.

**Permitting:** Water rights have to be available for a supply of recharge water. There are other water right and permitting issues that are currently ambiguous in the state of Washington, but these are currently being addressed in the rulemaking process for ASR.

**Surficial Geology/Hydrogeology:** Surface infiltration requires geologic units that provide sufficient infiltration and permeability capabilities. Areas with alluvium or unconsolidated sediments at the ground surface are favorable for surface infiltration. The hydrogeology of the aquifer system should be favorable for surface infiltration and passive recovery, including a shallow unconfined aquifer system that is hydraulically connected to a stream.

**Recharge Water Source:** A source of recharge water is required. Surface infiltration also requires close proximity to sources of water from infrastructure such as canals and ditches. The native groundwater and aquifer mass should be chemically compatible with the recharge water to prevent changes in the groundwater quality. Source water is typically surface water.


Reservoir
Stream
Infiltration Basin
Streamflow Augmentation
Surface Infiltration with No Recovery
FIGURE 2-2
SURFACE RECHARGE
ANCHOR/YAKIMA RVR BASIN STORAGE/WA
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Golder Associates

# 3.0 BACKGROUND

This section describes the project areas, surface water management control points, water demand, and hydrogeology of the Yakima River Basin. Groundwater storage projects must fit within the existing structure of water management within the basin. Projects are also limited to areas with suitable hydrogeology. A brief overview of the physical and legal framework within the Yakima River Basin is provided in this section.

## 3.1 PROJECT AREAS AND CONTROL POINTS

The suitability of project locations within the Yakima River Basin is influenced by the geology/hydrogeology, surface water control points, and the location of the existing canal network.

### 3.1.1 Sub-Basins

The Yakima River Basin is a 6,200 square mile ($mi^2$) area in south-central Washington. The basin contains three ecoregions: Cascades, Eastern Cascades, and Columbia Basin (Jones, et al., 2006). Tributaries to the Yakima River include eight major rivers and numerous smaller streams. The largest tributary to the Yakima River is the Naches River.

Six smaller structural basins, created by large east-west anticlinal ridges, were identified within the Yakima River Basin as part of a U.S. Geological Survey (USGS) study (Jones, et al., 2006). The sub-basins consist of broad, flat-bottomed valleys that slope gently towards the Yakima River. From the headwaters of the Yakima River, the basins are Roslyn, Kittitas, Selah, Yakima, Toppenish, and Benton (Figure 3-1). Figure 3-2 shows the geology of the Yakima River Basin, highlighting four of the six sub-basins which contain unconsolidated hydrogeologic materials.

### 3.1.2 USGS Streamflow Gauge Control Points

The USGS records streamflow of the Yakima and Naches rivers (Figure 3-2). The average yearly runoff at key locations with the basin is provided in Table 3-1. The average annual flow volume at the Parker gauge is 1,563,216 acre-feet. The Yakima River at Cle Elum, Naches River near Naches, and Yakima River at Parker gauges are used as TWSA control points. The TWSA, as interpreted by Reclamation, is "…the total water supply available for the Yakima River basin above [the Parker gauge] PARW, for the period April through September" (Reclamation, 2002). Therefore, the Parker gauge is the primary control point that influences the amount of water available for water right holders in the Yakima River Basin.

### 3.1.3 Irrigation Canal System

There are over 50 irrigation districts that have an entitlement to divert water above the Parker gauge; the Kennewick Irrigation District diverts water below the Parker gauge (Reclamation, 2002). Irrigation water is delivered to land within an irrigation district via irrigation canals and ditches. The Yakima Basin Project supplies water to 465,000 irrigated acres of land. The water is delivered to seven divisions according to supplemental water supply contracts: Kittitas (59,123 acres), Tieton (27,271 acres), Sunnyside (103,562 acres), Roza (72,511 acres), Kennewick (19,171 acres), Wapato (136,000), and supplemental water supply contracts (over 45,000 acres) (Reclamation, 2002). The water is delivered using an extensive canal system. The locations of canals in the Yakima River Basin are displayed on Figure 3-3.

## TABLE 3-1

Average Yearly Runoff at Key Locations

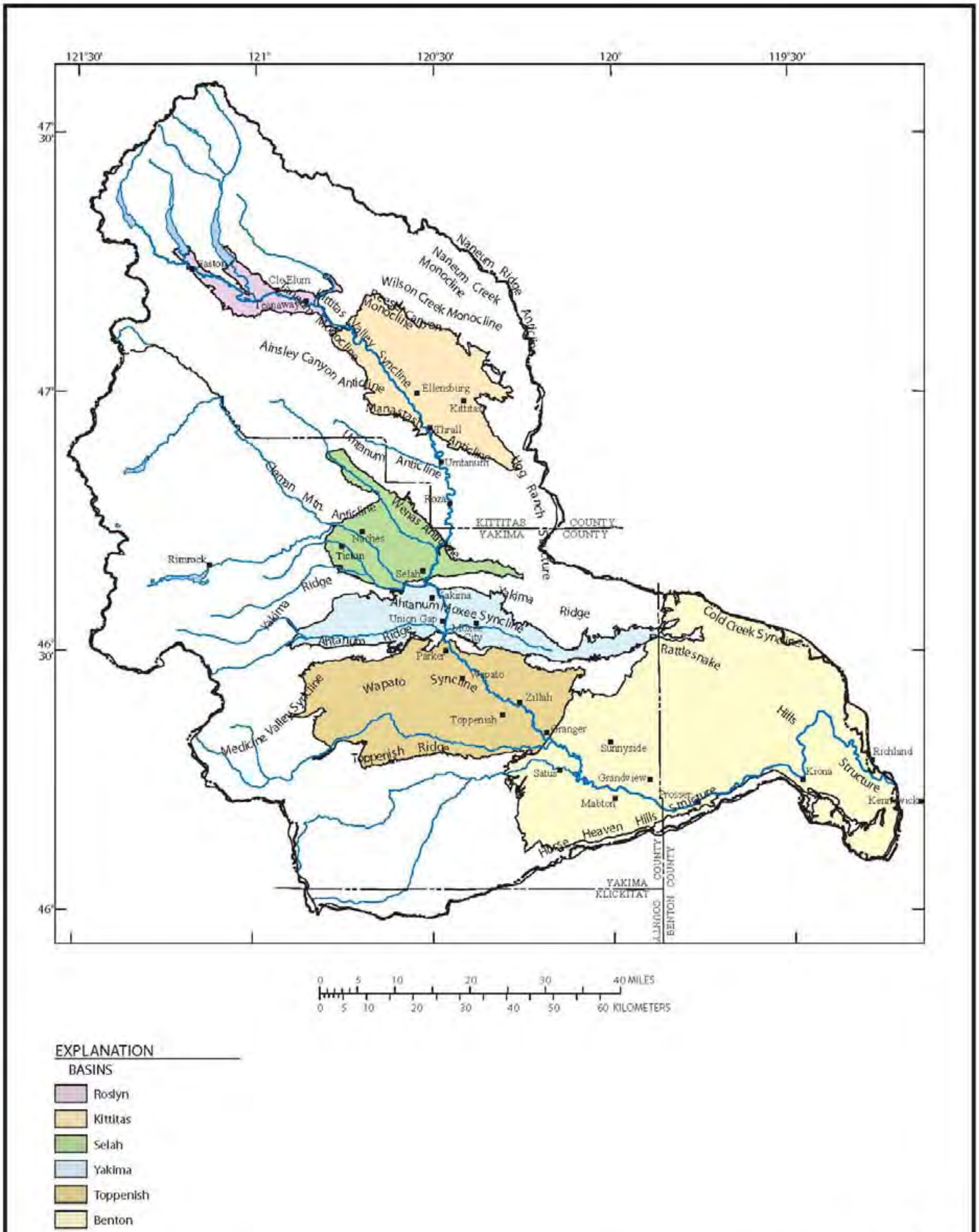
| Site | Average Yearly Runoff (Acre-Feet per Year) | |
|---|---|---|
| | 1961-1990 estimated unregulated flow[2] | 1961 - 1990 measured flow[3] |
| Yakima River near Easton | 651,000 | 342,215 |
| Yakima River at Cle Elum[1] | 1,478,000 | 1,183,648 |
| Yakima River at Umtanum | 2,007,000 | 1,750,128 |
| Naches River near Naches[1] | 1,234,000 | 838,606* |
| Yakima River at Parker[1] | 3,410,000 | 1,563,216 |
| Yakima River at Kiona | 3,970,000 | 2,475,950 |

Notes:

1. Total Water Supply Available (TWSA) control point.
2. Reclamation Surface Water Hydrology Model.
3. Reclamation records.

*Wapatox Power Plant diverts 257, 350 acre-feet per year up-stream of gauge.

Source: Reclamation (2002)




*Source: Jones, et al (2006)*

FIGURE **3-1**
**SIX SEDIMENTARY SUB-BASINS WITHIN THE YAKIMA BASIN**
ANCHOR/YAKIMA RVR BASIN STORAGE/WA

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**Golder Associates**

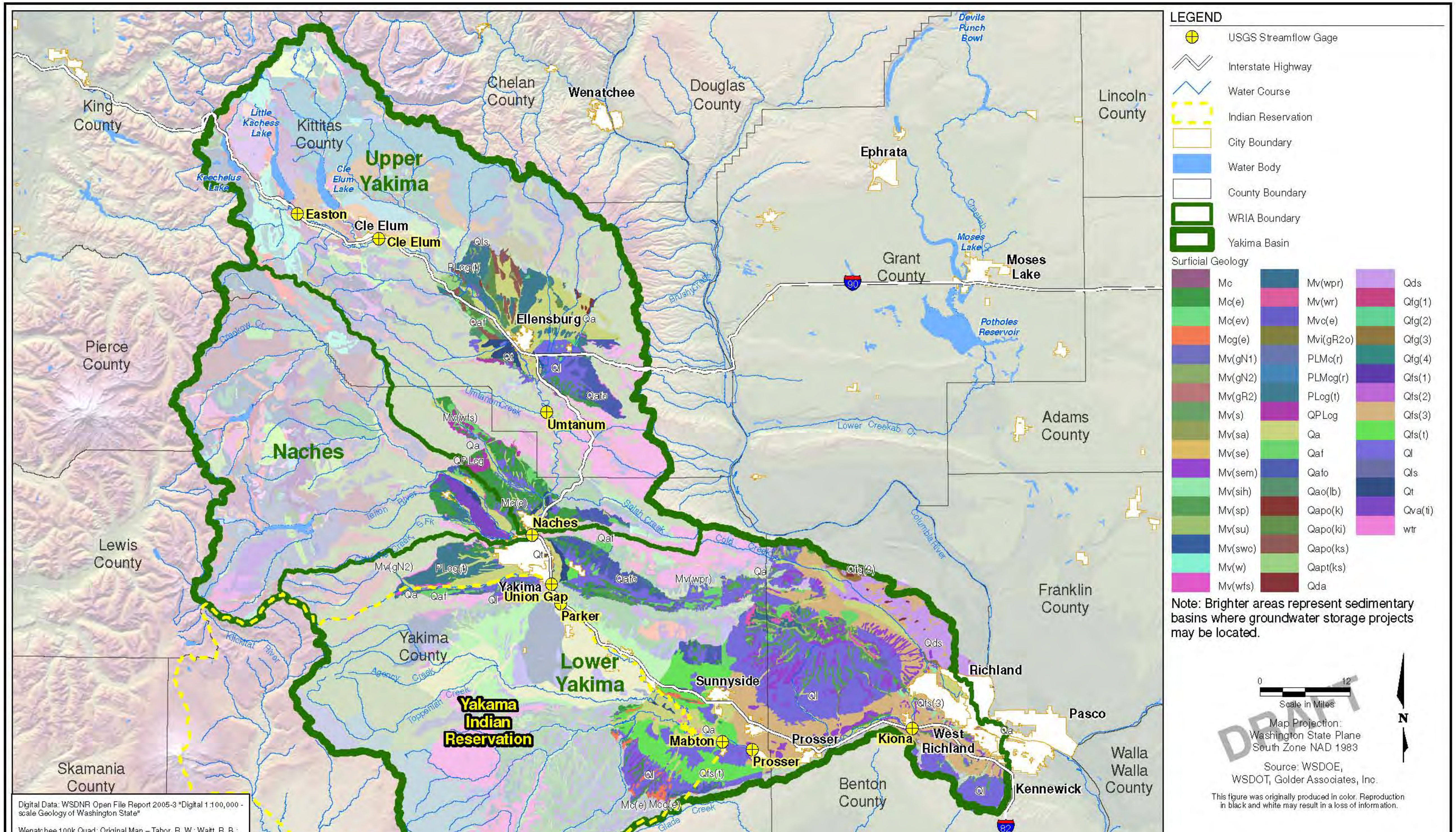


FIGURE **3-2**
**SURFICIAL GEOLOGY AND USGS STREAMFLOW GAUGES**
ANCHOR/YAKIMA RVR BASIN STORAGE/WA

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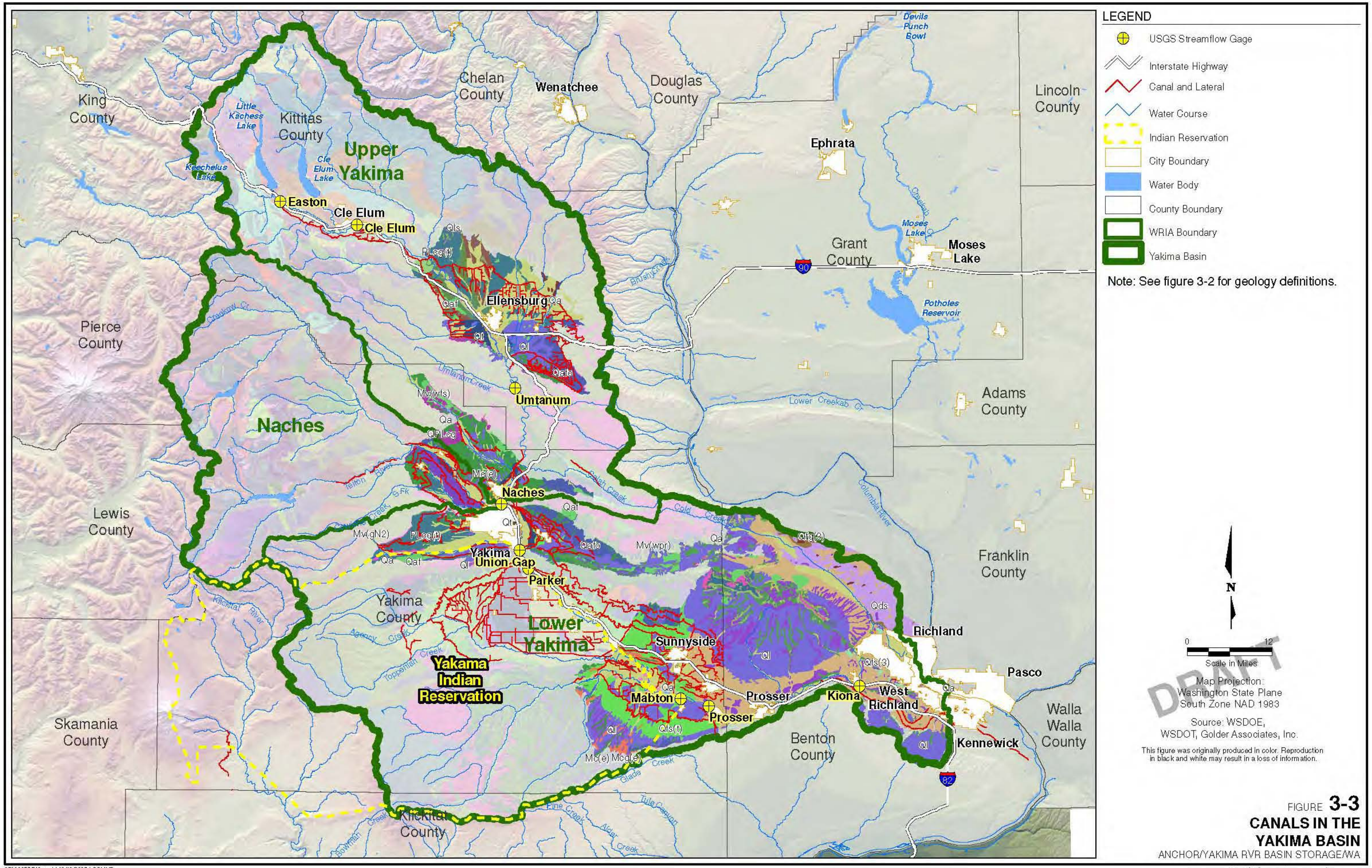



FIGURE 3-3
CANALS IN THE YAKIMA BASIN
ANCHOR/YAKIMA RVR BASIN STORAGE/WA
Golder Associates

## 3.2 WATER DEMAND

The existing demand for water in the basin includes instream flows, irrigation demand, and municipal demand. Water available to supply the demand is limited by the total water supply available at the Parker gauge.

### 3.2.1 Instream Flow Demand

The following discussion on instream flow requirements is from the 2003 Yakima Basin Watershed Plan (EES, et al., 2003). Instream flow requirements are based on court orders and federal legislation related to the Yakima Irrigation Project. The requirements include target flows mandated by Congress and Reclamation's instream target flows at various reaches in the river system. The state of Washington has not established minimum instream flows in the Yakima River Basin (EES, et al., 2003).

Target instream flows have been defined at two points in the Yakima River Basin, as mandated by Congress through the Yakima River Basin Water Enhancement Project (YRBWEP) (Title XII of the Act of October 31, 1994, U.S. Congress [Public Law 103-434]). The legislation states that the Yakima project superintendent shall estimate the water supply which is anticipated to be available to meet water entitlements, and provide instream flows in accordance with the criteria in Table 3-2. This new operational regime was institutionalized in 1995 but initiated by the Yakima project superintendent in 1992 before passage of the Title XII legislation. The target flows cover the months of April through September (irrigation season), but do not define flows for the remaining months of the year. Operational target flows for other times of year and locations are set by Reclamation in consultation with the Systems Operating Advisory Committee. Those operational target flows are negotiated annually and are based on biological needs of fisheries (EES, et al., 2003).

Target flows are defined in a way that requires they be increased as water conservation elements of YRBWEP are implemented over time. Table 3-2 displays the target flows at this time, without implementation of conservation elements; and what they would be if the conservation goals of YRBWEP were fully met (EES, et al., 2003).

### 3.2.2 Proratable Irrigation Demand

The following description of water delivery entitlements is from Reclamation's Interim Comprehensive Basin Operating Plan for the Yakima project (Reclamation, 2002). Water delivery entitlements for all major irrigation systems in the Yakima River Basin, except for the lower reaches of the Yakima River near the confluence with the Columbia River, were determined in the 1945 Consent Decree (Decree). The Decree states the quantities of water to which all project water users are entitled (maximum monthly and annual diversion limits) and defines a method of prioritization to be placed into effect during water-deficient years. The water entitlements are divided into two classes: nonproratable and proratable. Nonproratable entitlements are held by those water users with the earliest filed water rights, and these entitlements are to be served first from the TWSA. All other project water rights are proratable. They are of equal priority to each other, but second in line to the nonproratables. Any shortages that may occur are shared equally by the proratable water users (Reclamation, 2002). Flows at the Parker gauge control the amount of water available for nonproratable and proratable water rights (see Section 3.1.2). Historical estimates of TWSA from 1977 to 2000 are provided in Table 3-3.

**TABLE 3-2**

Target Flows at Sunnyside and Prosser Diversion Dams

| Water Supply Estimate[1] for Period (million acre feet) | | | | Target Flow (cfs) from date of estimate through October downstream of Sunnyside and Prosser Diversion Dams | |
|---|---|---|---|---|---|
| **April through September** | **May through September** | **June through September** | **July through September** | **Without Basin Conservation Program** | **With Basin Conservation Program** |
| 3.2 | 2.9 | 2.4 | 1.9 | 600 | 900 |
| 2.9 | 2.65 | 2.2 | 1.7 | 500 | 800 |
| 2.65 | 2.4 | 2 | 1.5 | 400 | 700 |
| <2.65 | <2.4 | <2.0 | <1.5 | 300 | 300[2] |

Notes:

(1) "Estimate" refers to the Project Superintendent's water supply estimate.
(2) Only increased with reduced diversions below Sunnyside.

Source: EES, et al. (2003)

Historically, (except Water Year (WY) 1993) the prorationing period has not started until the date of storage control. This means that water has been available for all entitlements until May. The amount of proration is determined monthly, biweekly, or as needed by project operations and this information is provided to water using entities at manager meetings. The nonproratable users can divert their full irrigation entitlements. This amount is deducted from the water supply available for irrigation entitlements with the remainder available for the proratable irrigation entitlements. The recognized quantities of nonproratable and proratable irrigation entitlements are summarized in Table 3-4. Proratable water users did not receive all of their proratable entitlement in 1992, 1993, 1994, 2001, and 2005 (Reclamation, 2002). One of the goals of increased storage in the Yakima River Basin is to provide a more reliable water source for the proratable water rights by increasing the total water supply available.

**TABLE 3-3**

Historical TWSA Estimates by Month in KAF, Commencing WY 1977 & YRBWEP Title XII Target flows in cfs, Commencing WY 1995.

| Month | Mar's Apr | | XII | Apr | | XII | May | | XII | Jun | | XII | | Jul | | XII | | Aug | | Sep | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| YEAR | KAF | Notes | cfs | KAF | Notes | cfs | KAF | Notes | cfs | KAF | Notes | cfs | Notes | KAF | Notes | cfs | Notes | KAF | Notes | KAF | Notes |
| 1977 | - | | - | 2,037 | | - | - | | - | - | | - | | - | | - | | - | | - | |
| 1978 | 3,088 | | - | 2,678 | | - | 2,341 | | - | - | | - | | 1,433 | | - | | 920 | | - | |
| 1979 | 2,770 | | - | 2,657 | | - | 2,460 | | - | 1,964 | | - | | - | | - | | - | | - | |
| 1980 | 3,268 | | - | 3,147 | | - | 2,705 | | - | 2,121 | | - | | - | | - | | - | | - | |
| 1981 | 2,690 | | - | 2,367 | | - | 2,296 | | - | 1,979 | | - | | - | | - | | - | | - | |
| 1982 | 3,433 | | - | 3,256 | | - | 3,005 | | - | - | | - | | - | | - | | - | | - | |
| 1983 | 3,453 | | - | 3,392 | | - | 2,941 | | - | 2,271 | | - | | - | | - | | - | | - | |
| 1984 | 2,956 | | - | 2,786 | | - | 2,501 | | - | 2,200 | | - | | - | | - | | - | | - | |
| 1985 | 3,106 | | - | 3,111 | | - | 2,868 | | - | 2,395 | | - | | 1,529 | | - | | 899 | | - | |
| 1986 | 3,061 | | - | 2,668 | | - | 2,284 | | - | 1,800 | | - | | 1,367 | | - | | - | | - | |
| 1987 | 2,558 | | - | 2,559 | | - | 2,297 | | - | 1,661 | | - | | 1,301 | | - | | - | | - | |
| 1988 | 2,377 | | - | 2,253 | | - | 2,065 | | - | 1,710 | | - | | 1,349 | | - | | - | | - | |
| 1989 | 2,946 | | - | 3,071 | | - | 2,666 | | - | 2,192 | | - | | - | | - | | - | | - | |
| 1990 | 3,446 | | - | 3,268 | | - | 2,824 | | - | 2,417 | | - | | 1,717 | | - | | - | | - | |
| 1991 | 2,938 | | - | 2,962 | | - | 2,742 | | - | 2,261 | | - | | 1,854 | | - | | - | | - | |
| 1992 | 2,853 | | - | 2,422 | | - | 2,268 | | - | 1,497 | 4 | - | | 1,155 | 1 | - | | 788 | 1 | 324 | 1 |
| 1993 | 2,062 | | - | 1,974 | 5 | - | 1,842 | 2 | - | 1,405 | 1,2 | - | | 1,126 | 1,2 | - | | 774 | 1,2 | 415 | 1,2 |
| 1994 | 2,169 | 2 | - | 2,016 | 2 | - | 1,691 | 2 | - | 1,191 | 1,2 | - | | 934 | 1,2 | - | | 593 | 1,2 | 283 | 1,2 |
| 1995 | 3,284 | 2 | 600 | 3,044 | 2 | 500 | 2,666 | 2 | 500 | 2,088 | 2 | 400 | | 1,572 | 2 | 400 | | - | | - | |
| 1996 | 3,268 | 2 | 600 | 2,872 | 2 | 400 | 2,530 | 2 | 400 | 2,003 | 2 | 400 | | 1,463 | 2 | 400 | | - | | - | |
| 1997 | 4,055 | 2 | 600 | 4,542 | 2 | 600 | 3,836 | 2 | 600 | 2,670 | 2 | 600 | | 1,935 | 2 | 600 | | - | | - | |
| 1998 | 3,193 | 2 | 500 | 2,982 | 2 | 500 | 2,548 | 2 | 400 | 2,017 | 1,2 | 400 | | 1,536 | 1,2 | 400 | | - | | - | |
| 1999 | 4,179 | 2 | 600 | 4,198 | 2 | 600 | 3,649 | 2 | 600 | 3,017 | 2 | 600 | | 1,913 | 1,2 | 600 | | - | | - | |
| 2000 | 3,319 | 2 | 604 | 3,305 | 2 | 604 | 2,691 | 2 | 5,046 | 2,175 | 2 | 404 | 3 | 1,615 | 2 | 404 | 3 | - | | - | |
| *Average* | *3,064* | | *-500* | *2,899* | | *-500* | *2,596* | | *-400* | *2,049* | | *-400* | | *1,487* | | *-300* | | *795* | | *341* | |

Notes:

XII = YRBWEP Title XII Target Flows – April (or current month) through October. KAF = thousand acre-feet

1. Based upon adopted forecast.
2. Does not include October's entitlements, runoff, or return flows.
3. Includes YRBWEP lease and acquisition (L&A) water.

Source: Reclamation (2002)

### 3.2.3 Municipal Demand Centers

There are fifteen municipalities within the Yakima River Basin. Seven of the municipalities use water above Parker gauge, and the other eight use water from below the Parker gauge (Figure 3-4). Figure 3-4 shows the location of each municipal diversion and return flow in relation to the Yakima River, its tributaries, and gauge locations. Figure 3-5 is a simplified version of Figure 3-4 that does not include the tributaries. The population of the Yakima River Basin was approximately 288,000 people in the year 2000. Based on projections developed for the 2003 Yakima Basin Watershed Plan, the basin's population is projected to increase to over 418,000 people by the year 2020, and 531,000 people by the year 2050 (EES, et al., 2003). Population growth will increase municipal water demand within the basin.

Water users obtain their water from municipal systems, small public water systems, individual household wells, and wells owned by self-supplied industrial users. Table 3-5 presents current (year 2000) and projected demands through year 2020 for municipal water systems (EES, et al., 2003). Municipal demands have been grouped by USGS streamflow gauge control point. The city of Yakima diverts the largest quantity of surface water for municipal use (>10 cfs), followed by the community of Cle Elum (approximately 1 cubic feet per second [cfs]), and other smaller diversions.

The estimated total additional volume of water needed to meet future municipal demand by the year 2020 for all of the municipalities listed in Table 3-5 is 25,438 acre-feet per year. This volume of water represents demand for additional potable water in the Yakima Basin. Some portion of the additional water needed by each municipality to support growth through 2020 represents the potential demand for municipal aquifer storage and recovery, which is discussed further in Section 5 for select municipalities.

Current and future rural residential water demand (not including municipal water demand) was also estimated for four subareas within the Yakima Basin as part of the watershed plan (EES, et al., 2003). Each of the subareas has been associated with the USGS streamflow gauge nearest to the mouth of the subarea. The Upper Yakima Subarea is associated with the Umtanum gauge, the Middle Yakima Subarea and Naches Subarea are associated with the Parker gauge, and the Lower Yakima Subarea is associated with the mouth of the Yakima Basin. The additional volume of water needed to meet future residential demand by the year 2020 for the users listed in Table 3-6 is 19,860 acre-feet per year. This volume of water represents demand for additional nonmunicipal potable water in the Yakima Basin.

Monthly shaping factors were used to distribute the annual volume of new municipal and residential water on a monthly basis (Tables 3-7 and 3-8). The shaping factors are based on monthly water production by the city of Yakima from 2004 to 2006 (Brown, personal communication, 2007). The monthly factors were assumed to be representative of municipal water use throughout the Yakima Basin; however, water demand from irrigation and permit-exempt wells may vary within the basin.

# TABLE 3-4

TWSA Irrigation Entitlements (af) recognized by 1945 Consent Decree
April 1st through September 30th, and October 1st through 30th

| Month | Nonproratable | Accumulated Nonproratable | Proratable | Accumulated Proratable | Monthly Total | Accumulated Remaining Entitlement |
|---|---|---|---|---|---|---|
| April | 160,973 | 1,070,271 | 93,857 | 1,239,199 | 254,830 | 2,309,470 |
| May | 186,637 | 909,298 | 228,463 | 1,145,342 | 415,100 | 2,054,640 |
| June | 182,240 | 722,661 | 258,150 | 916,879 | 440,390 | 1,639,540 |
| July | 189,640 | 540,421 | 268,236 | 658,729 | 457,840 | 1,199,150 |
| August | 186,058 | 350,817 | 257,822 | 390,493 | 443,880 | 741,310 |
| September | 164,759 | 164,759 | 132,671 | 132,671 | 297,430 | 297,430 |
| | | | | | | |
| October | 115,115 | 115,115 | 44,025 | 44,025 | 159,140 | 159,140 |

Notes:

1. Accumulated refers to the sum of all the remaining entitlements. For example the accumulated nonproratable amount for the month of April includes the nonproratable amounts for the months of April though September.

Source: Reclamation (2002)

**TABLE 3-5**

Current and Future Municipal Water Demand in the Yakima Basin

| Municipality | Estimated Year 2000 Water Use (acre-feet per year)[1] | Projected 2020 Future Water Use (acre-feet per year)[1] | Additional Water Needed to Support Growth through 2020 (acre-feet per year) |
|---|---|---|---|
| *Above Parker Gauge* | | | |
| Ellensburg | 4,820 | 7,062 | 2,242 |
| Cle Elum | 897 | 1,121 | 224 |
| City of Yakima | 17,151 | 19,393 | 2,242 |
| Nob Hill Water Association | 3,811 | 5,717 | 1,906 |
| Selah | 2,915 | 3,699 | 784 |
| Union Gap | 1,211 | 1,586 | 375 |
| Terrace Heights (Yakima County) | 673 | 1,233 | 560 |
| *Total Above Parker Gauge* | *31,478* | *39,811* | *8,333* |
| *Below Parker Gauge* | | | |
| Sunnyside | 3,251 | 4,260 | 1,009 |
| Grandview | 3,139 | 5,381 | 2,242 |
| Toppenish | 2,018 | 2,643 | 625 |
| Wapato | 1,345 | 3,139 | 1,794 |
| Benton City | 224 | 1,345 | 1,121 |
| Prosser | 3,139 | 3,924 | 785 |
| Richland | 9,192 | 15,358 | 6,166 |
| West Richland | 2,915 | 6,278 | 3,363 |
| *Total Below Parker Gauge* | *25,223* | *42,328* | *17,105* |

Notes:
1. Year 2000 water use estimate and projected 2020 water use from the 2003 Watershed Management Plan, Yakima River Basin (EES, et al., 2003). Water use estimates are based on average day demand.

## TABLE 3-6

Current and Future Residential Water Demand in the Yakima Basin[1]

| Location | Annual Demand (afy) | | Additional Water Needed to Support Growth through 2020 |
|---|---|---|---|
| | 2000 | 2020 | |
| *Upper Yakima Subarea* | | | |
| Other Community and Class B PWS (16) | 3,139 | 4,551 | 1,412 |
| Non-Community PWS (19) | 988 | 1,432 | 444 |
| Yakima Training Center (17) | 90 | 90 | 0 |
| Households with own well (18) | 5,652 | 8,195 | 2,543 |
| **Upper Yakima Total (Above Umtanum Gauge)** | 9,869 | 14,268 | 4,399 |
| *Middle Yakima Subarea* | | | |
| Other Community and Class B PWS (16) | 3,520 | 4,611 | 1,091 |
| Non-community PWS (19) | 173 | 226 | 53 |
| Yakima Training Center (17) | 90 | 90 | 0 |
| Households with own well (18) | 18,887 | 24,741 | 5,854 |
| *Naches Subarea (No systems with 1,000 connections)* | | | |
| Community and Class B PWS (16) | 1,487 | 2,022 | 535 |
| Non-Community PWS (19) | 680 | 925 | 245 |
| Households with own well (18) | 2,598 | 3,533 | 935 |
| **Naches and Middle Yakima Subtotal (Above Parker Gauge)** | 27,435 | 36,148 | 8,713 |
| *Lower Yakima Subarea* | | | |
| Other Community and Class B PWS (16) | 6,837 | 8,957 | 2,120 |
| Non-Community PWS (19) | 305 | 399 | 94 |
| Households with own well (18) | 14,627 | 19,161 | 4,534 |
| **Lower Yakima Subarea Subtotal (Above Mouth of Yakima Basin)** | 21,769 | 28,517 | 6,748 |
| **Total** | 59,073 | 78,933 | 19,860 |

Notes:

1. Year 2000 water use estimate and projected 2020 water use from the 2003 Watershed Management Plan, Yakima River Basin (EES, et al., 2003).

## TABLE 3-7

Seasonal Demand of Additional Water Needed to Support Municipal Growth through 2020 in the Yakima Basin

| Municipality | Annual (acre-feet per year)[1] | Seasonal Demand of Additional Water Needed to Support Growth through 2020 (acre-feet per month)[2] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| ***Above Umtanum Gauge*** | | | | | | | | | | | | | |
| Ellensburg | 2,242 | 99.6 | 93.8 | 110.1 | 152.3 | 224.4 | 273.4 | 313.6 | 296.9 | 241.4 | 184.7 | 138.8 | 112.9 |
| Cle Elum | 224 | 9.9 | 9.4 | 11.0 | 15.2 | 22.4 | 27.3 | 31.3 | 29.7 | 24.1 | 18.5 | 13.9 | 11.3 |
| ***Above Parker Gauge*** | | | | | | | | | | | | | |
| City of Yakima | 2,242 | 99.6 | 93.8 | 110.1 | 152.3 | 224.4 | 273.4 | 313.6 | 296.9 | 241.4 | 184.7 | 138.8 | 112.9 |
| Nob Hill Water Association | 1,906 | 84.7 | 79.7 | 93.6 | 129.5 | 190.8 | 232.4 | 266.6 | 252.4 | 205.2 | 157.0 | 118.0 | 96.0 |
| Selah | 784 | 34.8 | 32.8 | 38.5 | 53.3 | 78.5 | 95.6 | 109.6 | 103.8 | 84.4 | 64.6 | 48.5 | 39.5 |
| Union Gap | 375 | 16.7 | 15.7 | 18.4 | 25.5 | 37.5 | 45.7 | 52.4 | 49.7 | 40.4 | 30.9 | 23.2 | 18.9 |
| Terrace Heights (Yakima County) | 560 | 24.9 | 23.4 | 27.5 | 38.0 | 56.1 | 68.3 | 78.3 | 74.2 | 60.3 | 46.1 | 34.7 | 28.2 |
| ***Above Prosser Gauge*** | | | | | | | | | | | | | |
| Sunnyside | 1,009 | 44.8 | 42.2 | 49.6 | 68.5 | 101.0 | 123.0 | 141.1 | 133.6 | 108.7 | 83.1 | 62.5 | 50.8 |
| Grandview | 2,242 | 99.6 | 93.8 | 110.1 | 152.3 | 224.4 | 273.4 | 313.6 | 296.9 | 241.4 | 184.7 | 138.8 | 112.9 |
| Toppenish | 625 | 27.8 | 26.2 | 30.7 | 42.5 | 62.6 | 76.2 | 87.4 | 82.8 | 67.3 | 51.5 | 38.7 | 31.5 |
| Wapato | 1,794 | 79.7 | 75.1 | 88.1 | 121.9 | 179.6 | 218.7 | 250.9 | 237.6 | 193.2 | 147.8 | 111.1 | 90.4 |
| ***Above Kiona Gauge*** | | | | | | | | | | | | | |
| Benton City | 1,121 | 49.8 | 46.9 | 55.1 | 76.2 | 112.2 | 136.7 | 156.8 | 148.5 | 120.7 | 92.3 | 69.4 | 56.5 |
| Prosser | 785 | 34.9 | 32.8 | 38.6 | 53.3 | 78.6 | 95.7 | 109.8 | 104.0 | 84.5 | 64.7 | 48.6 | 39.5 |
| ***Above Mouth of Yakima Basin*** | | | | | | | | | | | | | |
| Richland | 6,166 | 273.9 | 258.0 | 302.9 | 418.9 | 617.3 | 751.8 | 862.4 | 816.6 | 664.0 | 508.0 | 381.8 | 310.6 |
| West Richland | 3,363 | 149.4 | 140.7 | 165.2 | 228.5 | 336.7 | 410.1 | 470.3 | 445.4 | 362.1 | 277.0 | 208.2 | 169.4 |
| **TOTAL** | **25,438** | **1,130** | **1,064** | **1,250** | **1,728** | **2,547** | **3,102** | **3,558** | **3,369** | **2,739** | **2,096** | **1,575** | **1,281** |

Notes:

1. Annual municipal water demand from Table 4-2. Represents additional water needed to support growth through 2020.

2. Seasonal municipal water demand approximated using domestic water use shaping factors from city of Yakima monthly average water production (2004-2006).

**TABLE 3-8**

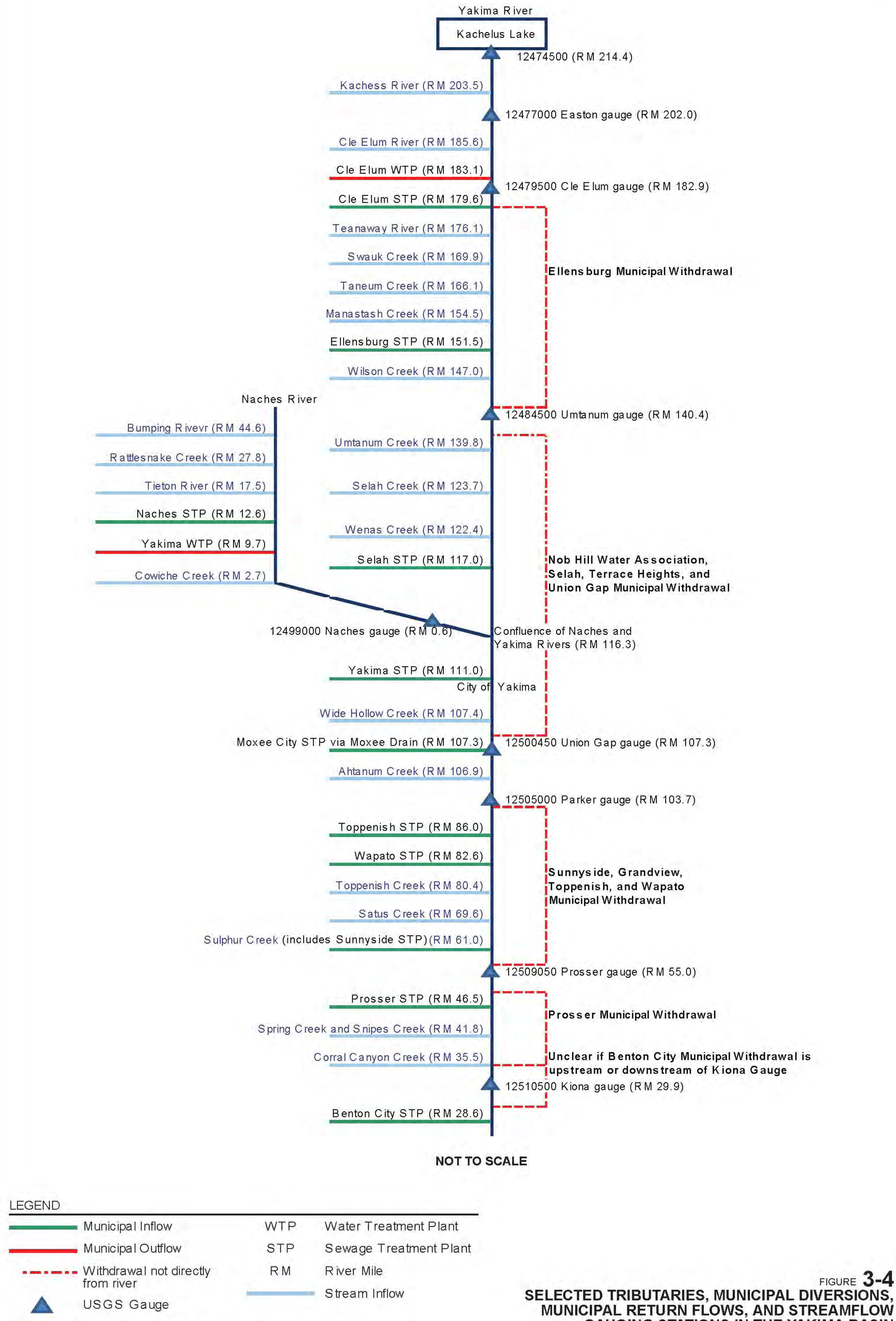
Seasonal Demand of Additional Water Needed to Support Residential Growth through 2020 in the Yakima Basin

| Location | Annual (acre-feet per year)[1] | Seasonal Demand of Additional Water Needed to Support Growth through 2020 (acre-feet per month)[2] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| *Upper Yakima Subarea* | | | | | | | | | | | | | |
| Other Community and Class B PWS (16) | 1,412 | 62.7 | 59.1 | 69.4 | 95.9 | 141.4 | 172.2 | 197.5 | 187.0 | 152.1 | 116.3 | 87.4 | 71.1 |
| Non-Community PWS (19) | 444 | 19.7 | 18.6 | 21.8 | 30.2 | 44.4 | 54.1 | 62.1 | 58.8 | 47.8 | 36.6 | 27.5 | 22.4 |
| Yakima Training Center (17) | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Households with own well (18) | 2,543 | 113.0 | 106.4 | 124.9 | 172.8 | 254.6 | 310.1 | 355.7 | 336.8 | 273.8 | 209.5 | 157.5 | 128.1 |
| **Upper Yakima Total** (Above Umtanum Gauge) | 4,399 | 195.4 | 184.1 | 216.1 | 298.8 | 440.4 | 536.4 | 615.2 | 582.6 | 473.7 | 362.4 | 272.4 | 221.6 |
| *Middle Yakima Subarea* | | | | | | | | | | | | | |
| Other Community and Class B PWS (16) | 1,091 | 48.5 | 45.6 | 53.6 | 74.1 | 109.2 | 133.0 | 152.6 | 144.5 | 117.5 | 89.9 | 67.6 | 55.0 |
| Non-community PWS (19) | 53 | 2.4 | 2.2 | 2.6 | 3.6 | 5.3 | 6.5 | 7.4 | 7.0 | 5.7 | 4.4 | 3.3 | 2.7 |
| Yakima Training Center (17) | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Households with own well (18) | 5,854 | 260.0 | 244.9 | 287.6 | 397.7 | 586.0 | 713.8 | 818.7 | 775.3 | 630.4 | 482.3 | 362.5 | 294.9 |
| *Naches Subarea (No systems with 1,000 connections)* | | | | | | | | | | | | | |
| Community and Class B PWS (16) | 535 | 23.8 | 22.4 | 26.3 | 36.3 | 53.6 | 65.2 | 74.8 | 70.9 | 57.6 | 44.1 | 33.1 | 26.9 |
| Non-Community PWS (19) | 245 | 10.9 | 10.3 | 12.0 | 16.6 | 24.5 | 29.9 | 34.3 | 32.4 | 26.4 | 20.2 | 15.2 | 12.3 |
| Households with own well (18) | 935 | 41.5 | 39.1 | 45.9 | 63.5 | 93.6 | 114.0 | 130.8 | 123.8 | 100.7 | 77.0 | 57.9 | 47.1 |
| **Naches and Middle Yakima Subtotal** (Above Parker Gauge) | 8,713 | 387.0 | 364.6 | 428.0 | 591.9 | 872.3 | 1062.4 | 1218.6 | 1153.9 | 938.3 | 717.8 | 539.5 | 438.9 |
| *Lower Yakima Subarea* | | | | | | | | | | | | | |
| Other Community and Class B PWS (16) | 2,120 | 94.2 | 88.7 | 104.1 | 144.0 | 212.2 | 258.5 | 296.5 | 280.8 | 228.3 | 174.6 | 131.3 | 106.8 |
| Non-Community PWS (19) | 94 | 4.2 | 3.9 | 4.6 | 6.4 | 9.4 | 11.5 | 13.1 | 12.4 | 10.1 | 7.7 | 5.8 | 4.7 |
| Households with own well (18) | 4,534 | 201.4 | 189.7 | 222.7 | 308.0 | 453.9 | 552.8 | 634.1 | 600.4 | 488.2 | 373.5 | 280.7 | 228.4 |
| **Lower Yakima Subarea Subtotal** (Above mouth of Yakima Basin) | 6,748 | 299.7 | 282.3 | 331.5 | 458.4 | 675.5 | 822.8 | 943.8 | 893.7 | 726.7 | 555.9 | 417.8 | 339.9 |

Notes:

1. Annual water demand from Table 4-3. Represents additional water needed to support growth through 2020.

2. Seasonal municipal water demand approximated using domestic water use shaping factors from city of Yakima monthly average water production (2004-2006).




*Source: Modified from Jones, et al (2006)*

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FIGURE **3-4**

**SELECTED TRIBUTARIES, MUNICIPAL DIVERSIONS, MUNICIPAL RETURN FLOWS, AND STREAMFLOW GAUGING STATIONS IN THE YAKIMA BASIN**

ANCHOR/YAKIMA RVR BASIN STORAGE/WA

**Golder Associates**

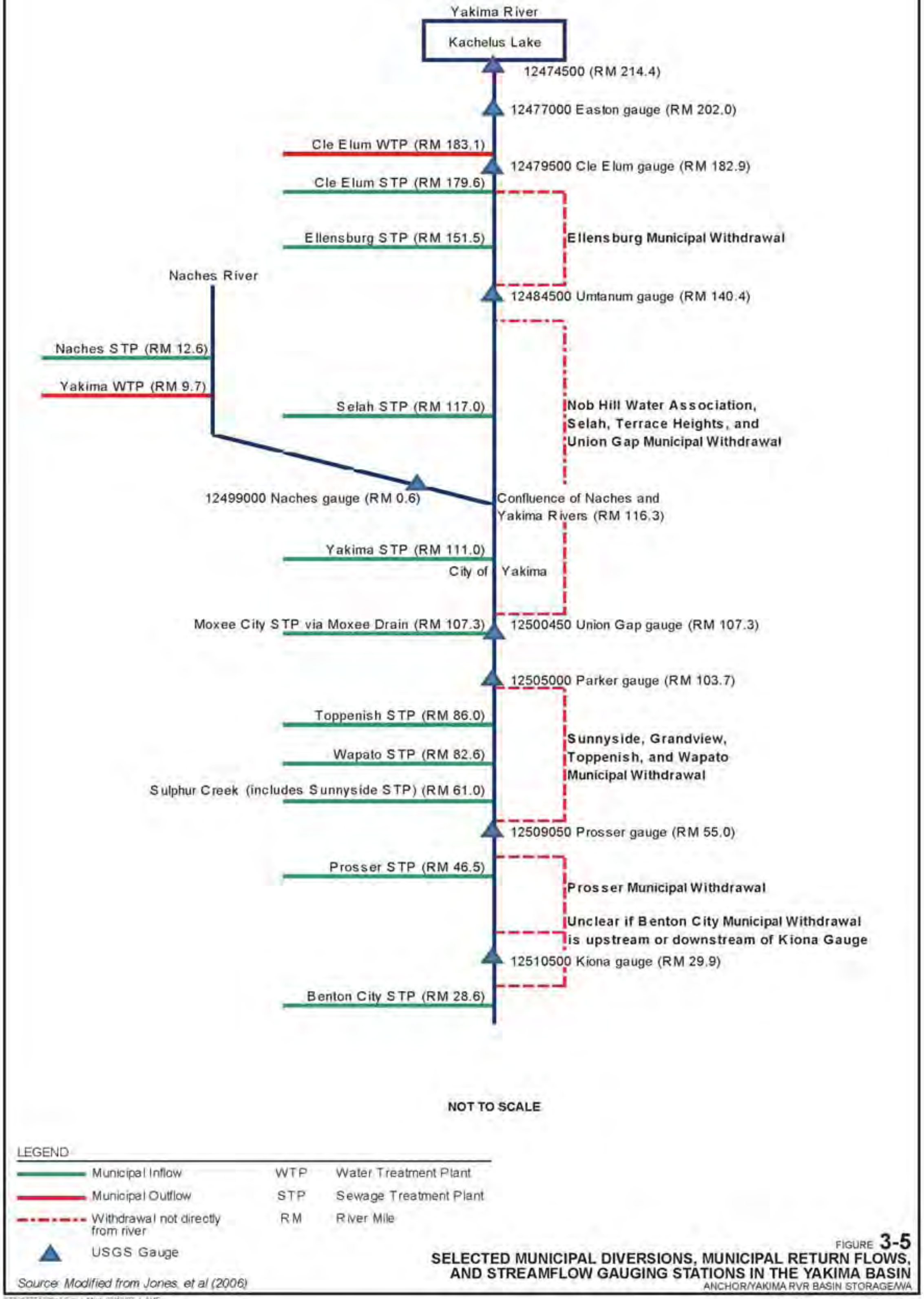


FIGURE 3-5
SELECTED MUNICIPAL DIVERSIONS, MUNICIPAL RETURN FLOWS, AND STREAMFLOW GAUGING STATIONS IN THE YAKIMA BASIN
ANCHOR/YAKIMA RVR BASIN STORAGE/WA

Golder Associates

## 3.3 HYDROGEOLOGY

This section describes the hydrogeologic units, aquifer properties, groundwater levels, and recharge to groundwater. These characteristics provide the basis for the groundwater storage feasibility assessment.

### 3.3.1 Hydrogeologic Units

A hydrogeologic unit can be characterized as either an aquifer or an aquitard (also referred to as a confining unit). An aquifer comprises saturated, permeable geologic units that are capable of transmitting useable quantities of water. Aquifers are classified as unconfined and confined. An aquitard is a unit that restricts the movement of groundwater.

Studies to quantify groundwater resources of the Yakima region normally define two to three aquifers based on lithological differences. Biggane (1982) considers two regional hydrogeologic units: a sedimentary aquifer and a basalt aquifer. Cearlock, et al. (1975) and Foxworthy (1962) refer to 1) a surficial gravel aquifer; 2) the Ellensburg Aquifer; and 3) the basalt aquifer. Both the sedimentary and basalt aquifers comprise a number of water-bearing and aquitard strata that possess different hydraulic properties.

In this study, a three aquifer classification is used (from surface down, youngest to oldest): Quaternary unconsolidated sediments/alluvium, the Ellensburg Formation, and Miocene basalts. These three classifications are discussed below.

- Quaternary unconsolidated sediments/alluvium range in thickness from a few feet to several tens of feet. The sediment consists of recent fluvial deposits from river and creek systems in the area, as well as scattered loess deposits associated with these fluvial systems. The other unconsolidated deposits also contain alluvial deposits, as well as fluvial, alluvial fan, colluvial, and other wind-blown deposits. Most wells in these units are for residential use.

- The Upper Ellensburg Formation has its greatest thickness at the center of the synclinal basins and thins against the slopes of the anticlinal basalt ridges. The sedimentary aquifer ranges in thickness from about 300 feet to 2,000 feet and can be divided into three units: upper, middle, and lower. The upper member of the Upper Ellensburg Formation attains depths of 900 feet and contains wells used for domestic, irrigation, and commercial/industrial purposes. The middle Ellensburg confining unit comprises interbedded clays, silts, and fine sands between 100 to 400 feet thick. Some wells have screened intervals that span more permeable zones within this layer. The lower Ellensburg confining unit comprises a number of semiconnected water producing zones with different confining pressures. The principal water producing zones occur in weakly cemented permeable layers of gravel and well-sorted sand. Although yields can be high if extensive coarse-grained layers are penetrated, the confined zone is generally not as permeable as the unconfined aquifer and tends to have lower yields. A limited number of wells are completed in this layer.

- The basalt aquifer underlies the sedimentary aquifer and also comprises a number of water-bearing and aquitard zones.  Aquifer zones occur within joints, fractured and brecciated units of the Columbia River Basalt Group (CRBG), as well as in interbedded sedimentary layers (e.g., the Selah member of the Lower Ellensburg Formation). Aquitard zones comprise competent basalt between the flow tops and bottoms and major joints.

### 3.3.2 Groundwater Levels

The National Water Information System (NWIS) contains the well log database developed for the Yakima River Basin Project by the USGS.  Over 1,900 wells were identified in the project area.  The wells were then categorized according to total depth and depth to water.  Wells were broken into categories based on water depth and total well depth.  Figure 3-6 shows the location of selected wells that are less than 200 feet deep and the maximum depth to water measured from 2000 to 2001, where available.  Hydrographs of water levels in unconsolidated and consolidated sedimentary deposits for selected wells are provided in Appendix A. Hydrographs of the water levels in wells completed in the confined basalt group are also provided in Appendix A.

### 3.3.3 Aquifer properties

Groundwater exists and is analyzed relative to its dynamic state (i.e., its ability to move through the subsurface) and its static state (i.e., the volume of water that exists at a given point in time). Groundwater moves through an aquifer in relation to hydraulic boundaries, such as rivers or lakes, and moves from higher elevation to lower elevation.  The transmissivity of an aquifer is measured because it describes how easily water moves through the aquifer: its dynamic component.  Transmissivity is the best indicator of well production and is therefore frequently reported in water supply studies.  Many methods for determining transmissivity have been developed over the years and they account for a variety of hydrogeologic settings.  The storage coefficient of an aquifer describes the static component of the aquifer: the volume of water within the pore spaces of the aquifer formation.  Storage coefficients are more difficult to measure in an aquifer.  Aquifer transmissivity and storage coefficient together are used to describe the time-varying dynamics of an aquifer system and how it responds to recharge, pumping, or other stresses.

When a well is initially pumped, water is withdrawn from the pore spaces in the aquifer.  The behavior of an aquifer during injection or controlled recharge is analogous (but inverse) to pumping.  During the early stages of pumping, the static storage volume in the aquifer is providing a relatively large proportion of the water to the well.  As pumping continues over time, the influence of the well extends outward from the well to hydraulic boundaries of the aquifer system, eventually establishing an equilibrium within the dynamics of the aquifer as a whole (i.e., the recharge and discharge continuum).  Therefore, during the later stages of pumping, the dynamic flowing volume in the aquifer provides a relatively large proportion of the water to the well.  Accordingly, a long-term continuous groundwater withdrawal generally causes a permanent change to the recharge-discharge equilibrium of an aquifer, which is often reflected as a decrease in stream base flow.

Estimates of the storativity and specific yield within the Yakima River Basin were obtained for confined and unconfined aquifers. Storativity values are based on a literature review of storativity values for basalt aquifers. Values for the Wanapum basalts (Deobald, et al., 1995) and a generalized confined aquifer (Barnett, 2000) provide a reasonable range for storativity that is between 0.00002 and 0.0005.

A reasonable range of the specific yield of alluvium and unconsolidated sediments that comprise the unconfined aquifers, based on the range of glaciofluvial material, is 0.03 to 0.2 (Whiteman, et al., 1994). The materials in the shallow Yakima River Basin are comprised of coarser materials which would have a higher specific yield. Silts and fine sands tend to occur deeper in the sedimentary sequence and correspond more to lacustrine deposits, which have a lower specific yield.

The hydraulic conductivity of the alluvium and unconsolidated sediments ranges from 5.1 to 26 feet per day based on the median and 75$^{th}$ percentile of the hydraulic conductivity estimates of overburden in the Columbia Basin (Hansen, et al., 1994). The median and 75$^{th}$ percentile are representative of the coarse-grained character along many sections of the streams in the basin.

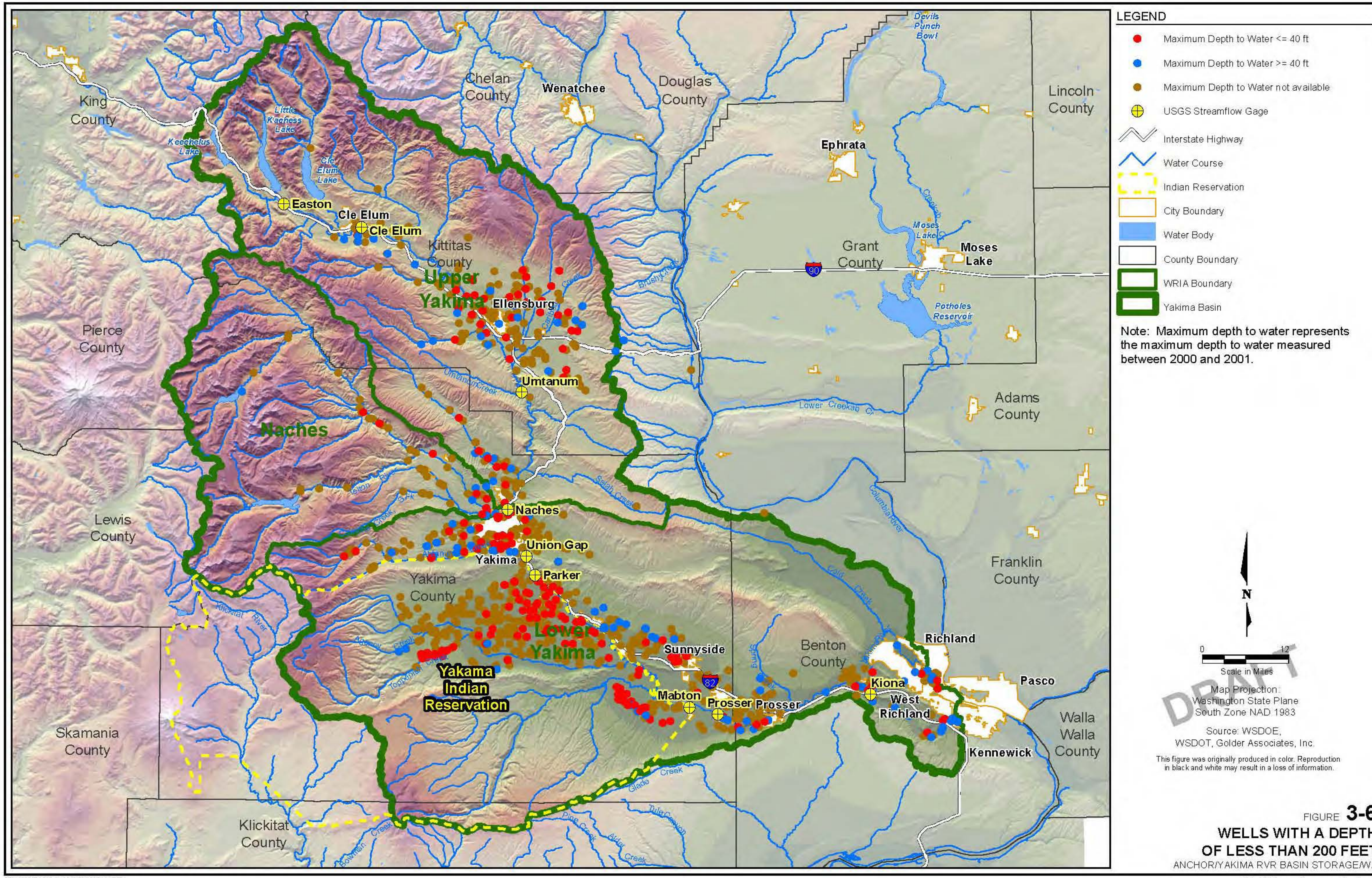


FIGURE 3-6
WELLS WITH A DEPTH OF LESS THAN 200 FEET

### 3.3.4 Recharge

A USGS study of groundwater recharge under pre- and post-development conditions in the Yakima River Basin provided the following summary of the groundwater recharge in the Yakima River Basin (Vaccaro and Olsen, 2007). The USGS used two models to estimate groundwater recharge to the Yakima River Basin aquifer system for predevelopment conditions (estimate of natural conditions) and current conditions (a multiyear, 1995 to 2004, composite). Daily values of recharge were estimated for water years 1950 to 1998 using Precipitation-Runoff Modeling System (PRMS) watershed models for four mainly forested upland areas. Water years 1950 to 2003 were evaluated using the Deep Percolation Model applied to 17 semiarid to arid areas in the basin (Vaccaro and Olsen, 2007). Figure 3-7 shows the annual recharge for water year 2001 in the Yakima River Basin.

The mean annual recharge under predevelopment conditions was estimated to be about 11.9 inches or 5,450 cubic feet per second (cfs) (about 3.9 million acre-feet) for the 6,207 $mi^2$ in the modeled area. Within the modeled area, recharge ranged from 0.08 inch (1.2 cfs) to 34 inches (2,825 cfs). About 90 percent of the total recharge occurred in the upper Yakima and Naches modeled areas (Vaccaro and Olsen, 2007).

The mean annual recharge to the aquifer system under current conditions was estimated to be about 15.6 inches, or 7,149 cfs (about 5.2 million acre-feet). The increase in recharge is due to the application of irrigation water to croplands. The annual quantity of irrigation was more than five times the annual precipitation for some of the modeled areas. Mean annual actual evapotranspiration was estimated to have increased from predevelopment conditions by more than 1,700 cfs (about 1.2 million acre-feet) due to irrigation (Vaccaro and Olsen, 2007).

Groundwater in the basalt is recharged directly by infiltration along the anticlinal ridges and along losing reaches of rivers where the basalt is exposed at the surface. The basalt aquifer is also recharged by downward flow from the sedimentary aquifer in portions of the basin, principally along the edge of basins. Groundwater in the alluvium is recharged by infiltration of precipitation, seepage from streams, irrigation canals and irrigated land and upward leakage from confined aquifers.

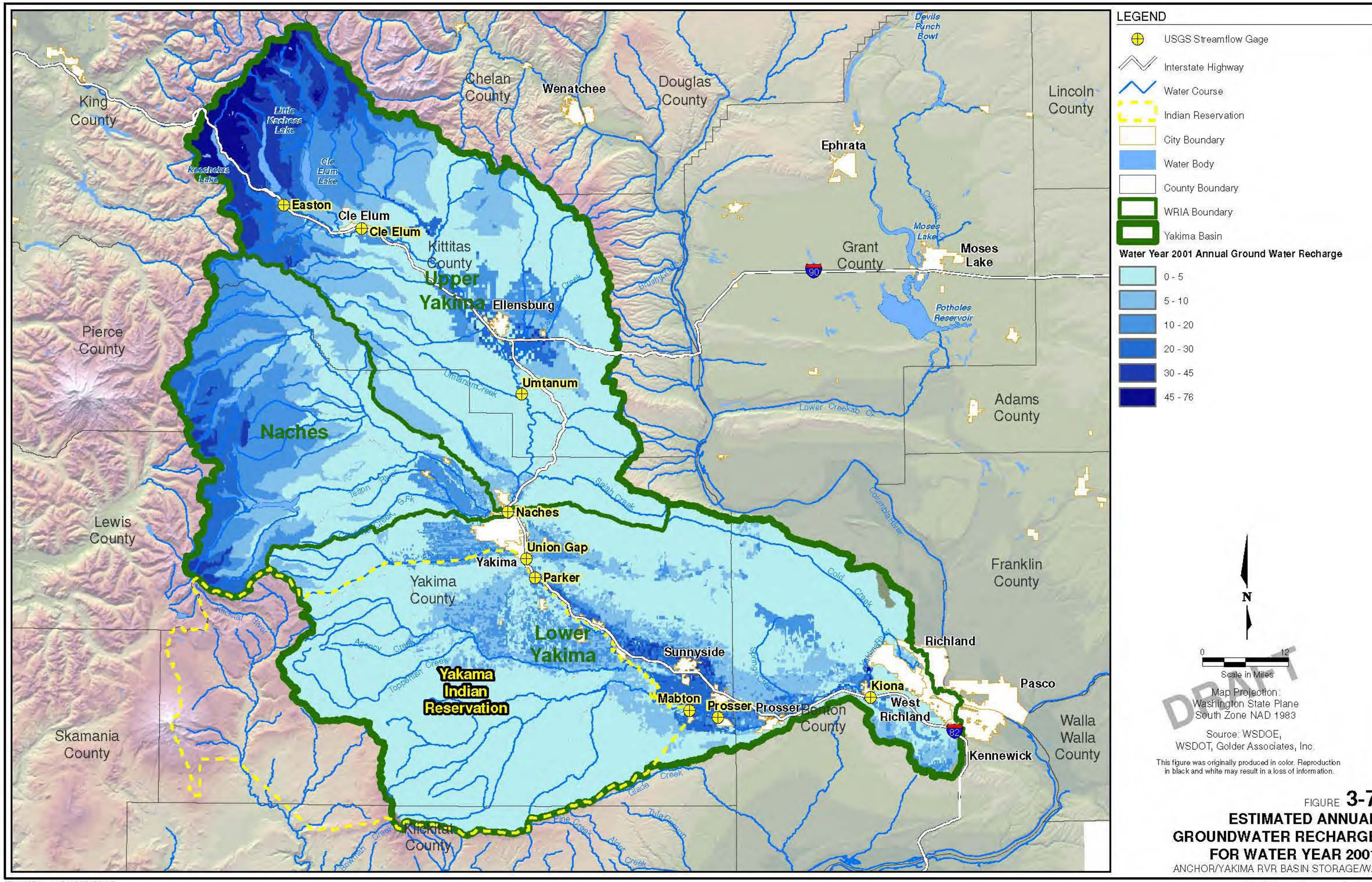


FIGURE 3-7
ESTIMATED ANNUAL GROUNDWATER RECHARGE FOR WATER YEAR 2001

# 4.0 SURFACE RECHARGE WITH PASSIVE RECOVERY

The surface recharge analysis considered the characteristics and volumes of water needed or available for infiltration and subsequent return flow, focusing on the ability to increase streamflows during July, August, and September. The analysis identified a range of total acres of land needed based on a range of assumptions about the geology and aquifer properties. Specific sites were not identified for surface recharge locations because of the lack of site-specific hydrogeologic data. Instead a map of the possible locations for sites was developed that could be used with more site-specific data.

## 4.1 METHODOLOGY

The approach for evaluating surface recharge includes several components outlined below and shown on Table 4-1 and Figure 4-1. An infiltration pond would receive water from the irrigation canal system and infiltrate to groundwater. The groundwater would discharge to an adjacent stream and an "accretion" of flow would occur. The groundwater storage capacity for surface recharge is reflected in the combined capability of the pond to store and infiltrate water and the ability of the aquifer to transmit and discharge the water back to the river. The volume analyses described in Sections 4.2 through 4.5 are based on a monthly time step. Details at a smaller time step (e.g., days or weeks) are not evaluated.

The four components to the methodology are as follows:

1. Infiltration Capacity (Section 4.2). This describes a range of pond capacities that could be expected in the Yakima River Basin. The analysis is based on standard analytical equations and suggested approaches in the Washington Department of Transportation Design Manual for infiltration facilities (WSDOT, 2006).

2. Return Flow Processes (Section 4.3). This describes the volume and timing of the infiltration that reaches the groundwater table and moves from beneath the infiltration pond to a discharge zone (i.e., a stream or river). The analysis is based on an analytical model (SDF View), developed by Colorado State University (2005).

3. Potential Site Locations (Section 4.4). The aquifer properties, surficial geology, land cover, range of infiltration areas, and return flow processes are considered to evaluate the potential for infiltration in specific areas of the Yakima Valley. However, specific sites are not identified.

4. Surface Recharge Return Flow Volumes (Section 4.5). This section combines the various components into a month-by-month estimate of return flow volumes from surface recharge using two approaches to determine delivery volumes to the infiltration ponds.

## 4.2 INFILTRATION CAPACITY AND VOLUMES

The ability to infiltrate water from a pond is determined by a number of factors, including the area and geometry of the pond, infiltration capacity of the soil, depth to groundwater, and ponding depth. Two approaches were used to estimate infiltration capacity. The results of these estimates suggest that an average infiltration capacity of 20 to 60 acre-feet (AF) per acre per month would be reasonable to expect for the study area. Based on these infiltration capacities, an area of 166 to 500 acres of land would be required to infiltrate 10,000 AF of water in one month.

Details of the infiltration estimates are as follows:

A representative 20-acre infiltration pond with a ponding depth of 2 to 5 feet was assumed, and a series of infiltration estimation equations were used to estimate the infiltration capacity (Washington Department of Transportation Design Hydraulics Manual, 2006, Chapter 4-5 Infiltration Design Guidance). Key parameters used in the equations are summarized on Table 4-2. Based on these calculations, infiltration capacities of 30 to greater than 100 acre-feet/acre per month are estimated.

A corollary analysis was made using actual performance data for five large infiltration facilities in Arizona. Since 1997, the Central Arizona Project (CAP) has designed and constructed five large infiltration facilities to infiltrate surface water for groundwater recharge. Currently, these five facilities encompass approximately 400 acres and have the capacity to infiltrate 12,650 acre-feet of water per month. Table 4-3 summarizes some of the design information for these facilities, and Appendix C contains more detailed information on each facility. The operational results at these facilities indicate an infiltration capacity of greater than 50 AF/acre per month. Some facilities have achieved much higher specific infiltration rates (e.g., greater than 100 AF/acre/month).

The time that it takes for infiltration to move from the ground surface to the water table is expected to vary from days to weeks. An estimate of one month is assumed. The infiltration profile used to evaluate return flow volume and timing is discussed in Section 4.5.

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A representative 20-acre infiltration pond with a ponding depth of 2 to 5 feet was assumed, and a series of infiltration estimation equations were used to estimate the infiltration capacity (Washington Department of Transportation Design Hydraulics Manual, 2006, Chapter 4-5 Infiltration Design Guidance). Key parameters used in the equations are summarized on Table 4-2. Based on these calculations, infiltration capacities of 30 to greater than 100 acre-feet/acre per month are estimated.

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The time that it takes for infiltration to move from the ground surface to the water table is expected to vary from days to weeks. An estimate of one month is assumed. The infiltration profile used to evaluate return flow volume and timing is discussed in Section 4.5.

## TABLE 4-1

Timing of Delivery, Infiltration, and Beginning of Return Flows (Accretion) to River

| Month | | Jan 31 | Feb 31 | Mar 28 | Apr 30 | May 31 | Jun 30 | Jul 31 | Aug 31 | Sep 30 | Oct 31 | Nov 30 | Dec 31 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| May | Delivery to Infiltration Pond | | | | | X | | | | | | | |
| | Infiltration Pond to Aquifer | | | | | | | | | | | | |
| | Aquifer Discharge to Stream | | | | | | | | | | | | |
| Jun. | Delivery to Infiltration Pond | | | | | | X | | | | | | |
| | Infiltration Pond to Aquifer | | | | | | | | | | | | |
| | Aquifer Discharge to Stream | | | | | | | | | | | | |
| Jul. | Delivery to Infiltration Pond | | | | | | | X | | | | | |
| | Infiltration Pond to Aquifer | | | | | | | | | | | | |
| | Aquifer Discharge to Stream | | | | | | | | | | | | |
| Aug. | Delivery to Infiltration Pond | | | | | | | | X | | | | |
| | Infiltration Pond to Aquifer | | | | | | | | | | | | |
| | Aquifer to Stream | | | | | | | | | | | | |
| Sept. | Delivery to Infiltration Pond | | | | | | | | | X | | | |
| | Infiltration Pond to Aquifer | | | | | | | | | | | | |
| | Aquifer Discharge to Stream | | | | | | | | | | | | |
| Oct. | Delivery to Infiltration Pond | | | | | | | | | | X | | |
| | Infiltration Pond to Aquifer | | | | | | | | | | | | |
| | Aquifer Discharge to Stream | | | | | | | | | | | | |

Notes:

(grey) Indicates time over which infiltration from pond to aquifer is occurring.

(blue) Indicates time over which the accretion to the river is occurring. Accretion to the river also extends into the following year.

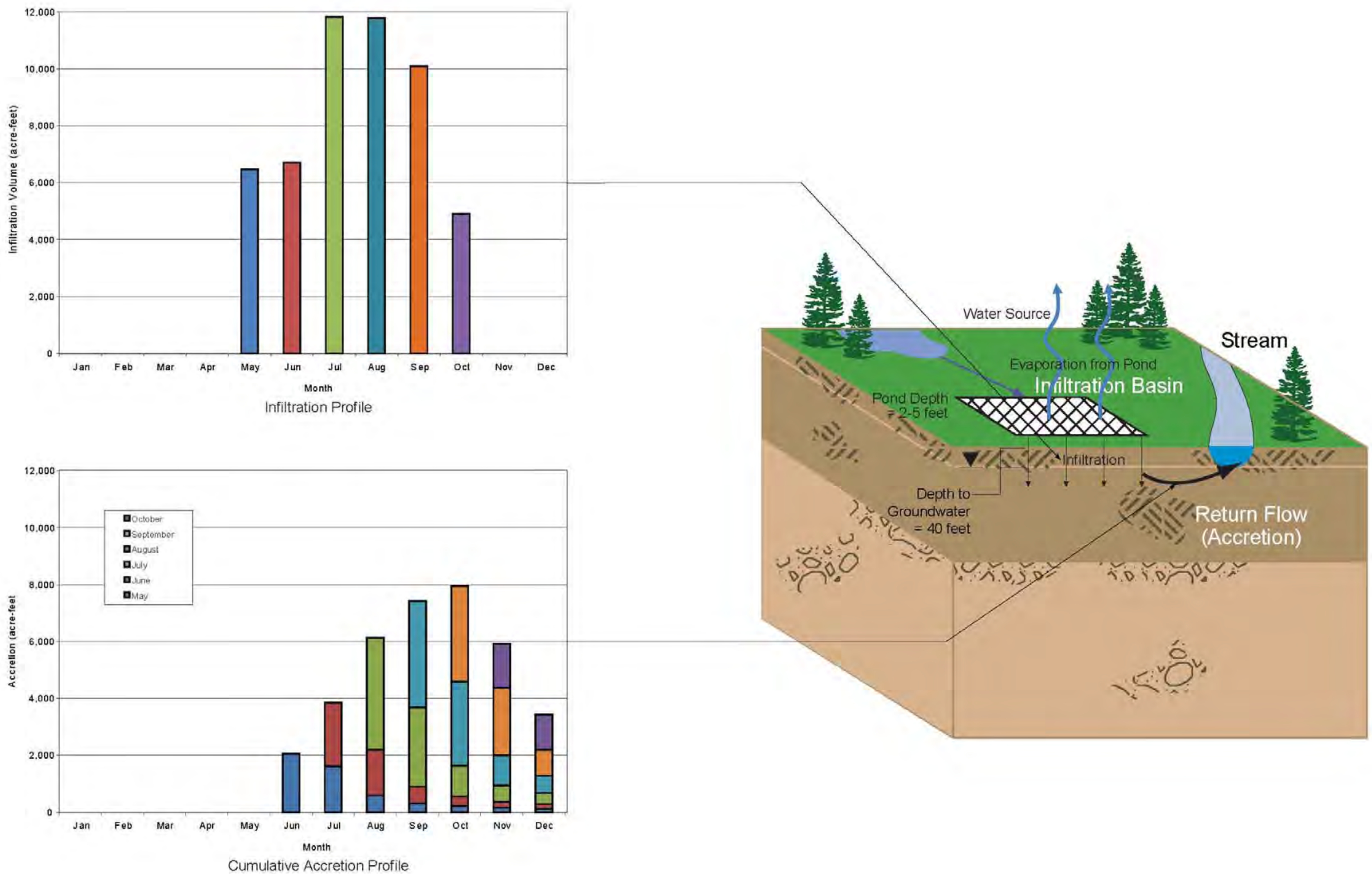


FIGURE 4-1
SURFACE RECHARGE SCHEMATIC
ANCHOR/YAKIMA RVR BASIN STORAGE/WA

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## 4.3 RETURN FLOW ANALYSIS

The relationship between the pumping of a well and the resulting depletion of a nearby stream has been derived by several investigators (Theis, 1941; Conover, 1954; Glover and Balmer, 1954; Glover, 1960; Theis and Conover, 1963; Hantush, 1964, 1965). The effects of recharge are identical to the effects of pumping except the direction of flow is reversed (Jenkins, 1968). The return flow to the stream from surface recharge is defined as the "accretion" to the river, as opposed to depletion from the river. The terms stream depletion, or stream depletion factor (SDF), are used in the literature, and for the analysis in this report the term SDF is used in the context of return flow or accretion to the river.

A program called SDF View, version 2.0.11 (Colorado State University, 2005) was used to solve the analytical equations that determine the rate and volume of return flow from a given rate and volume of infiltration. The SDF approach assumes that the infiltration has reached the water table and uses a SDF factor that is a function of the distance between a site and a stream, the transmissivity of the aquifer, and the specific yield of the aquifer. A SDF value and time series of infiltration volumes are input into the SDF program to generate a stream accretion function, which estimates the timing and volume of accretion to a river from the recharge to an aquifer. The equation used to calculate the SDF value is:

$$SDF = \frac{x^2 S}{T}$$ , where

x = effective distance from the infiltration basin to the surface water source (ft)
S = specific yield (dimensionless)
T = transmissivity ($ft^2$/day)

The SDF value has units of days. The SDF View analysis is based on the following assumptions:

- The aquifer is unconfined, isotropic, homogeneous, and semi-infinite with a constant transmissivity.
- The stream is of constant temperature, and can be represented by a linear boundary that fully penetrates the aquifer.
- Water is added instantaneously to storage, and the infiltration rate is uniform over the time-step of the analysis.
- There are no other losses or gains to streamflow from pumping or return flows. For this study, the analysis therefore represents the additional accretion to a stream that would result from surface infiltration.

**TABLE 4-2**

Key Parameters Used in the Infiltration Pond Equations

| | |
|---|---|
| Length of Pond Bottom (ft) | 1,500 |
| Width of Pond Bottom (ft) | 600 |
| Area of Bottom of Pond (acres) | 20 |
| Pond Side Slopes (3:1 typical) | 3 |

| Depth of Pond, Dpond | Depth to Water Table, Dwt | Hydraulic Conductivity, Kequiv[1] | Area of Pond Bottom, Apond | Hydraulic Gradient, i[2] | CFsize[3] | Size Adjusted Infiltration Rate, f[4] | CFaspect[5] | CFsilt/bio[6] | Performance Adjusted Infiltration Rate, fcorr | Infiltration Capacity | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (ft) | (ft) | ft/day | acres | | | ft/day | | | ft/day | Acre-ft/day | AF/mo | AF/Acre/Mo |
| 3 | 100 | 10 | 20 | 0.35 | 0.07 | 3.50 | 1.03 | 0.8 | 2.88 | 60 | 1,812 | 91 |
| 3 | 50 | 10 | 20 | 0.25 | 0.07 | 2.50 | 1.03 | 0.8 | 2.06 | 43 | 1,294 | 65 |
| 3 | 30 | 10 | 20 | 0.15 | 0.07 | 1.50 | 1.03 | 0.8 | 1.24 | 26 | 777 | 39 |
| | | | | | | | | | | | | |
| 3 | 100 | 5 | 20 | 0.35 | 0.07 | 1.75 | 1.03 | 0.8 | 1.44 | 30 | 906 | 45 |
| 3 | 50 | 5 | 20 | 0.25 | 0.07 | 1.25 | 1.03 | 0.8 | 1.03 | 22 | 647 | 32 |
| 3 | 30 | 5 | 20 | 0.15 | 0.07 | 0.75 | 1.03 | 0.8 | 0.62 | 13 | 388 | 19 |

Notes:

1. Hydraulic conductivity is consistent with USBR groundwater modeling, which used an average K of 5.8E-4 ft/sec for sediments in the Black Rock area.
2. Hydraulic gradient is conservatively estimated to be less than 1.0 and increases slightly with $D_{wt}$ (Massmann, 2003). Actual gradients could be higher which would result in higher infiltration.
3. CFsize is a correction factor based on Eq. 4-15 in WSDOT Manual. Cfsize approaches 1.0 for small ponds and decreases for larger ponds.
4. Size Adjusted Infiltration Rate, f, is based on Darcy's Law (f = K*i).
5. Cfaspect is a correction factor based on Eq.4-17 in WSDOT Manual and corrects for the ratio of length to width for the pond.
6. CFsilt/bio is a correction factor to account for siltation and biofouling (Table 4-11 in WSDOT Manual). A value of 0.9 indicates a low potential for biofouling and an average to high degree of maintenance and performance monitoring.

## TABLE 4-3

Design Information for Infiltration Facilities Associated with the Central Arizona Project

| Facility | Basin Dimensions | Infiltration Rates | Infiltration Volumes | Infiltration Capacity | Evaporation Loss | Cost |
|---|---|---|---|---|---|---|
| | **Total Acres** | **Ft/Day** | **Peak (AF/Mo)** | **AF per Acre per Month** | **%** | |
| | | | | | | |
| Agui Fria[1] | 100 | 1.2 - 3.5 | 5,000 | 50 | 0.5 - 1.0 | $10.5 M |
| Avra Valley[2] | 10.8 | 2.1 - 3.5 | 850 | 79 | <1 | $0.8M |
| Hieroglyph Mountains[3] | 38 | 3.0 - 6.0 | 2,800 | 73 | <1 | $5.5M |
| Santa Cruz[4] | 30 | N/A | 3,977 | 132 | <1 | $3.9 M |
| Pima Mine Road[5] | 14 | 0.7 - 4.2 | 2,000 | 142 | <1 | $11M |
| Superstition Mountains[6] | N/A | 4.0 - 7.0 | N/A | | N/A | N/A |
| Tonapah[7] | 206 | N/A | N/A | N/A | N/A | N/A |

Notes
1. Completed in 2003. Seven basins each about 6 feet deep. Depth to groundwater ranges from 30 to 100 ft.
2. Completed in 1998. Four basins (1.8 to 3.5 acres), 12 cfs peak inflow.
3. Completed in 2003. Seven basins, 50 cfs peak inflow.
4. Completed in 2004. Three basins (7 to 11 acres), 60 cfs peak inflow.
5. Completed in 2001. Two pilot basins (7 acres each), three expansion basins (7 to 15 acres)
6. In pilot testing phase.
7. In feasibility phase.

The SDF View program calculates return flow after the recharge stops. The decay curve of return flow after recharge stops varies with the SDF value. A smaller SDF value results in a rapid decay in return flow volume, while a larger SDF value results in a more uniform decay in return flow volume. SDF values of 30, 40, 50, and 60 days were used in the analysis. These values would result in larger volumes of same season return flow.

There were not enough data available to identify specific sites and SDF properties for surface recharge. Site identification will require a site investigation, including drilling and aquifer testing to obtain estimates of the hydrogeologic properties. However, a screening of potential areas was conducted based on surficial geology, land cover, estimated aquifer properties, and distance buffers around the Yakima River and main tributaries.

Areas shown to be alluvium or unconsolidated sediments at the ground surface were initially identified as having potential for surface recharge. Refer to Figure 3-2 for the distribution of geologic units. Aquifer transmissivity is the product of the thickness of the aquifer unit and the hydraulic conductivity. The thickness of the aquifer unit was determined using Geographic Information System (GIS) maps developed as part of the U.S. Geological Survey report on the hydrogeology of the Yakima River Basin (Jones, et al., 2006). The range of thicknesses was determined for the basins with unconsolidated sediments: Kittitas, Selah, Yakima, and Benton. The maximum total thickness of the unconsolidated sediments in each basin is 790 feet for Kittitas, 290 feet for Selah, 350 feet for Yakima, and 870 feet for Benton (Jones, et al., 2006). The total thickness of saturated alluvium and unconsolidated sediments was based on an assumed depth to water of 40 feet. A depth to water of 40 feet represents the average maximum depth to water measured in the wells identified in Figure 3-6. Appendix A contains the USGS (Jones, et al, 2006) isopach maps for the various units.

The hydraulic conductivity (K) of alluvium and/or unconsolidated sediments in the Yakima River Basin ranges from 5.1 to 26 feet/day (Hansen, et al., 1994). Specific yield ranges from 0.03 to 0.2 (Whiteman, et al., 1994). Keeping the distance and the aquifer thickness constant, a low SDF factor is obtained using the minimum S (0.03) and maximum K (26 feet/day), and results in a rapid decay of return flow volumes after recharge stops. A high SDF factor is obtained using the maximum S (0.2) and minimum K (5.1 feet/day), and results in a more uniform decay of return flow volumes after recharge stops. Intermediate combinations (maximum S/maximum K and minimum S/minimum K) result in intermediate SDF values. These four combinations of aquifer properties were therefore used with the maximum aquifer thickness in each basin to evaluate the distance needed between an infiltration pond and the stream to achieve the four SDF values (Table 4-4).

**TABLE 4-4**

Estimated Range in Maximum Distance from Stream for an Infiltration Site

| Stream Depletion Factor (days)[2] | Range in Maximum Distance from Stream (feet)[1] | | | |
|---|---|---|---|---|
| | Above Parker Gauge | | Below Parker Gauge | |
| | Kittitas | Selah | Yakima | Benton |
| 30 | 760 - 4,430 | 437 - 2,550 | 517 - 2,839 | 797 - 4,645 |
| 40 | 875 - 5,100 | 505 - 2,944 | 562 - 3,278 | 920 - 5,364 |
| 50 | 980 - 5,705 | 565 - 3,291 | 629 - 3,665 | 1,029 - 5,997 |
| 60 | 1,070 - 6,250 | 618 - 3,606 | 689 - 4,015 | 1,127 - 6,570 |

Notes:

1. The range is based on the different combinations of specific yield and hydraulic conductivity using the maximum thickness of the unconsolidated materials in each basin. Figure 4-2 maps the maximum distance buffer for each sub-basin. For example, only land within 6,250 feet of a stream in the Kittitas Basin is shown on the map.

2. The stream depletion factor is used in the context of return flow or accretion to the river. The equation used to calculate the SDF value is

$$SDF = \frac{x^2 S}{T}$$ , where

x = effective distance from the infiltration basin to the surface water source (ft)
S = specific yield (dimensionless)
T = transmissivity ($ft^2$/day)

A smaller SDF value results in a rapid decay in return flow volume, while a larger SDF value results in a more uniform decay in return flow volume. SDF values of 30, 40, 50, and 60 days were used in the analysis. These values would result in a larger volume of same season return flow.

## 4.4 POTENTIAL SURFACE RECHARGE AREAS

Areas suitable for surface infiltration will depend on surficial geology, SDF buffer distance, and land cover characteristics. The general areas that are expected to be suitable for surface recharge sites are shown on Figure 4-2. These locations were delineated based on the following:

- Surficial geology: The extent of the unconsolidated aquifers identified in the hydrogeologic mapping by Jones et al. (2006).

- Optimum SDF buffer distance: The maximum distance from the stream that would achieve an SDF value of between 30 and 60. Areas outside of this buffer will not achieve a SDF value of between 30 and 60 under the range of potential aquifer properties and thicknesses present in each basin. An SDF value of between 30 and 60 is optimum because it provides a larger same-season return flow to the stream.

Figure 4-2 shows that the largest areas with optimum recharge conditions are located in the Kittitas and Yakima sub-basins.

Land cover was also considered in evaluating where suitable recharge sites could be located using the National Land Cover Dataset (USGS, 1999). Land cover was grouped into general categories of natural vegetation, barren, commercial/industrial/transportation, high intensity residential, low intensity residential, nonirrigated agriculture, orchard/vineyard, other irrigated agriculture, fallow, water, and wetland (Figure 4-3). Areas that are currently classified as natural vegetation, nonirrigated agriculture, or fallow are considered more likely to be suitable for conversion to infiltration ponds.

Figures 4-4, 4-5, and 4-6 show the surficial geology within the SDF buffer distance in the Kittitas, Selah, Yakima, and Benton sub-basins. The locations of existing wells and the range in depth to water are also provided on the maps. The areas along Taneum Creek, Manastash Creek, Yakima River, Caribou Creek, Coleman Creek, Naneum Creek, and Swauk Creek have been identified in the Kittitas sub-basin as potential surface recharge areas (Figure 4-4). The buffer area contains a large amount of natural vegetation and other irrigated agriculture.

Areas along the Yakima River, Wenas Creek, Naches River, and Cowiche Creek have been identified in the Selah sub-basin as potential surface recharge areas (Figure 4-5). The buffer area contains a large amount of natural vegetation and orchard/vineyard land.

Areas along the Yakima River and Ahtanum Creek have been identified in the Yakima sub-basin as potential surface recharge areas (Figure 4-5). The buffer area contains a large amount of natural vegetation and orchard/vineyard land.

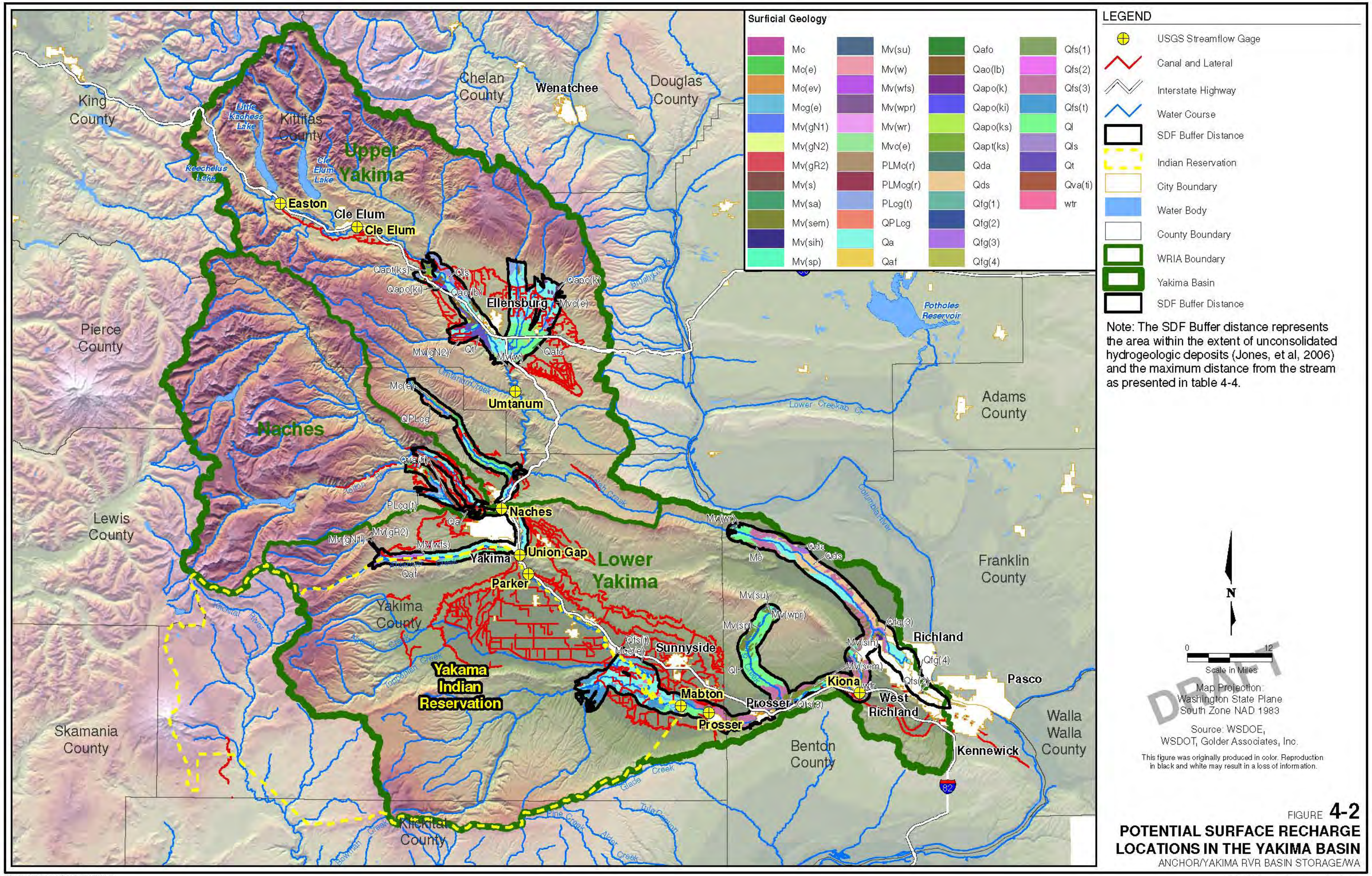


FIGURE 4-2
**POTENTIAL SURFACE RECHARGE LOCATIONS IN THE YAKIMA BASIN**
ANCHOR/YAKIMA RVR BASIN STORAGE/WA
Golder Associates

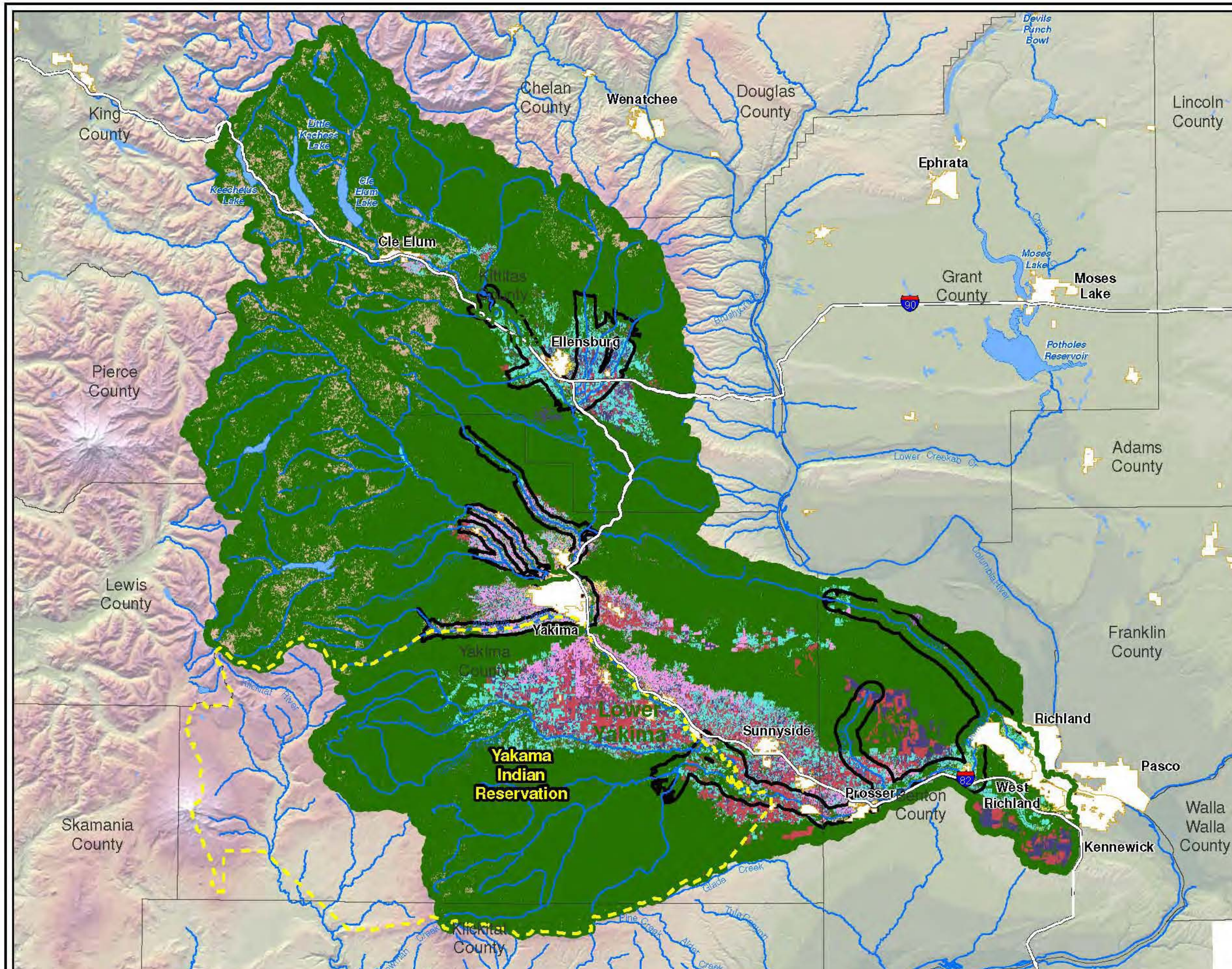


FIGURE **4-3**
**YAKIMA RIVER BASIN**
**LAND COVER CHARACTERISTICS**
ANCHOR/YAKIMA RVR BASIN STORAGE/WA
**Golder Associates**

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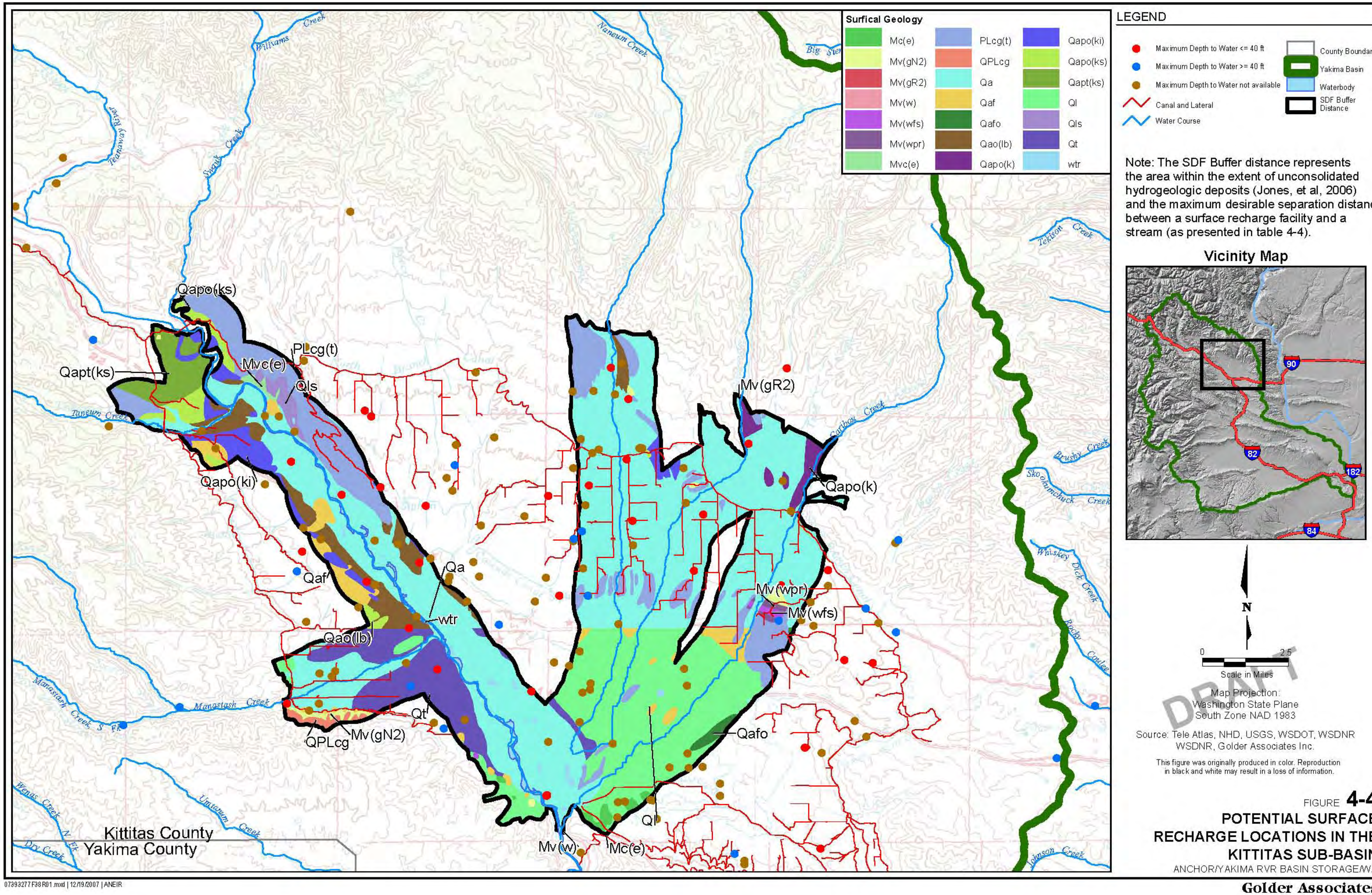



FIGURE 4-4
POTENTIAL SURFACE RECHARGE LOCATIONS IN THE KITTITAS SUB-BASIN

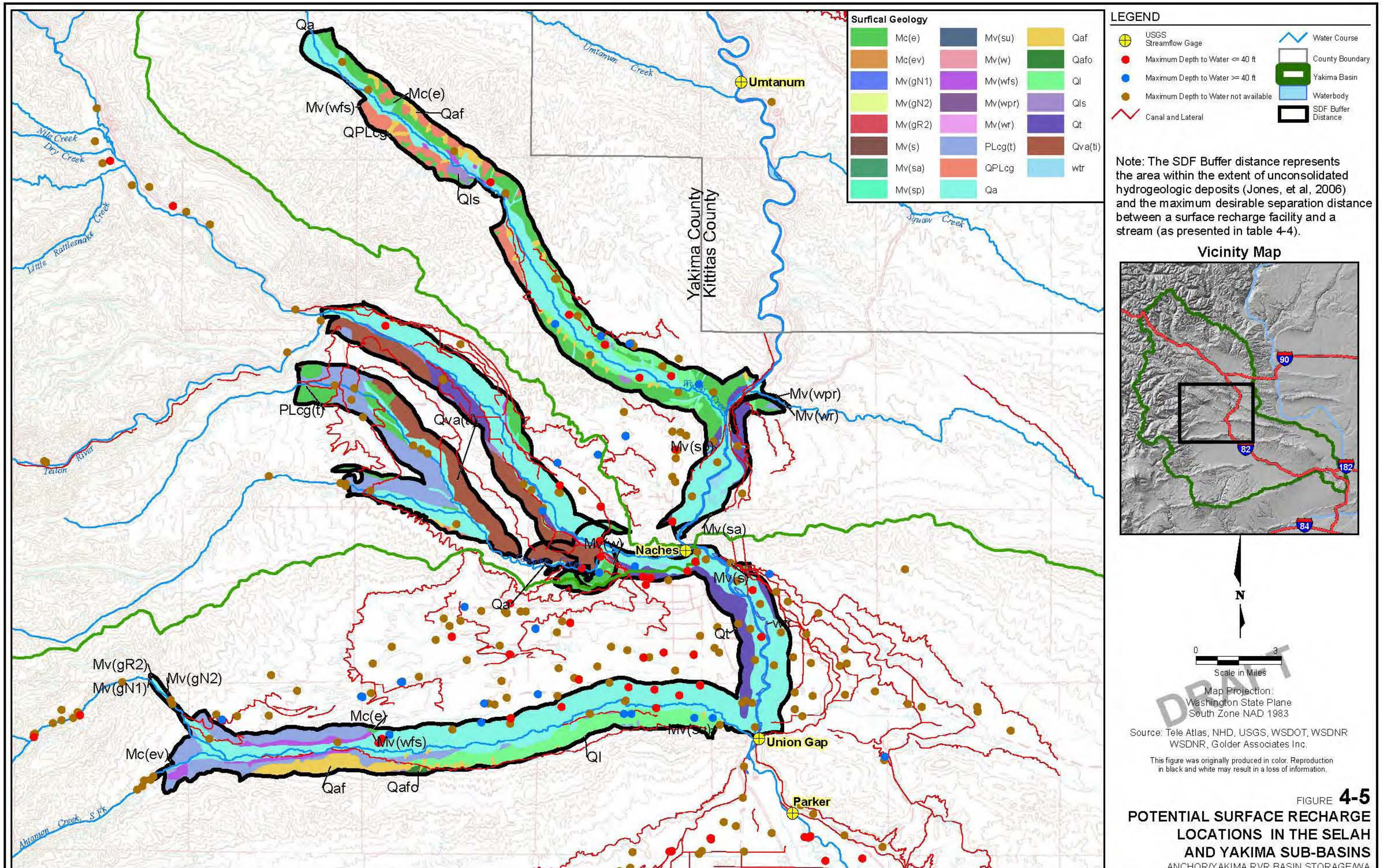



FIGURE **4-5**

**POTENTIAL SURFACE RECHARGE LOCATIONS IN THE SELAH AND YAKIMA SUB-BASINS**

ANCHOR/YAKIMA RVR BASIN STORAGE/WA

**Golder Associates**

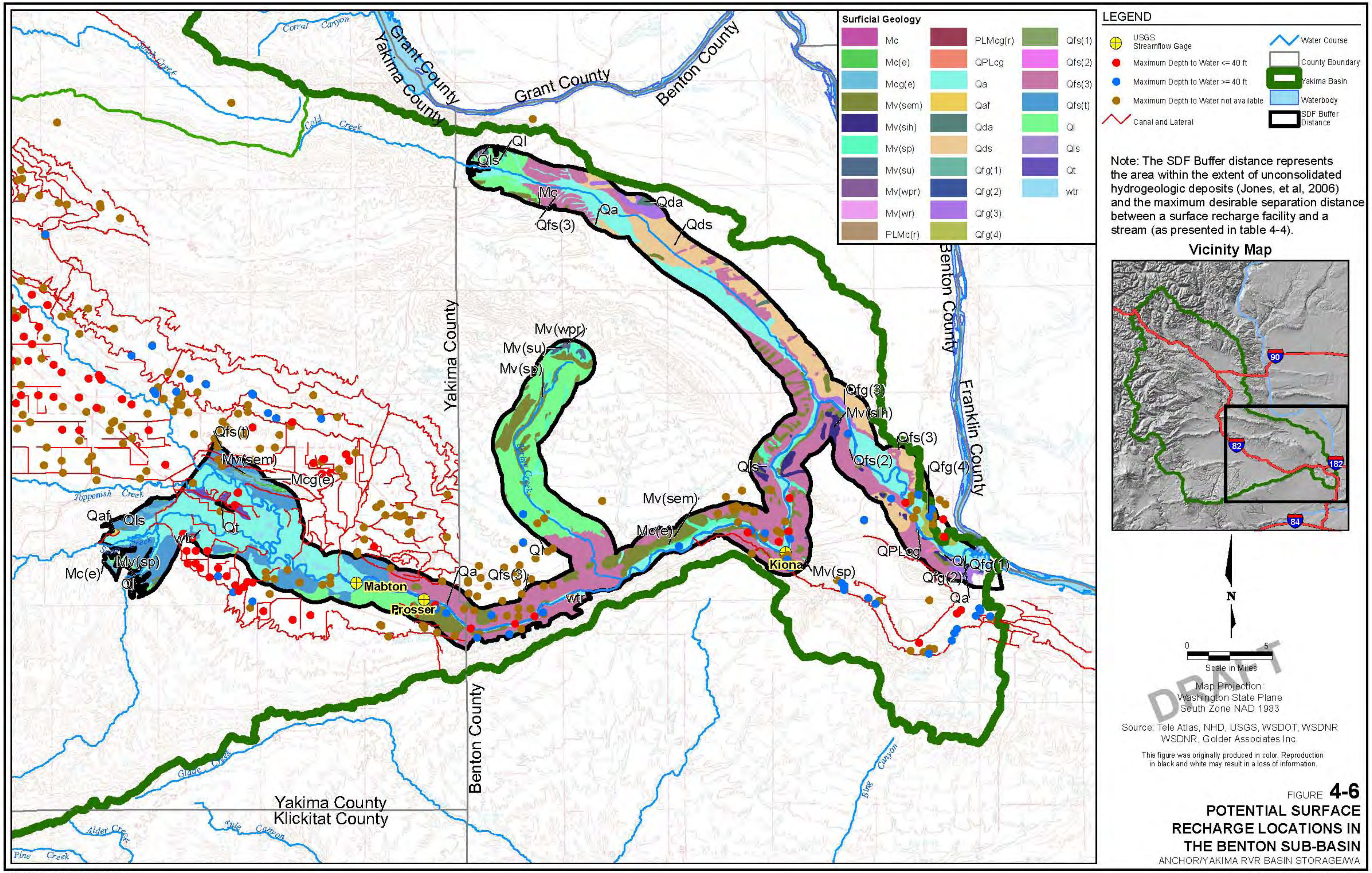



FIGURE **4-6**
**POTENTIAL SURFACE RECHARGE LOCATIONS IN THE BENTON SUB-BASIN**
ANCHOR/YAKIMA RVR BASIN STORAGE/WA
**Golder Associates**

Suitable locations in the Benton sub-basin (Figure 4-6) are located along the Yakima River, Toppenish Creek, Satus Creek, Spring Creek, and Cold Creek. The large amount of land along Cold Creek that is suitable for surface infiltration should not be considered for surface recharge sites. The confluence of Cold Creek and the Yakima River is downstream of Benton City and the Kiona gauge. There are also no existing canals within that area. The accretion from surface infiltration in that area would have a limited benefit and would not significantly contribute to improving water availability or instream flows of the Yakima River. The buffer area (without the Cold Creek area) contains a large amount of natural vegetation and nonirrigated agriculture.

## 4.5 SURFACE RECHARGE RETURN FLOW VOLUMES

The volume and timing of water diverted to an infiltration pond and the subsequent timing and volume of return flow to the stream was evaluated using the following two approaches:

1. Target Return Flow Profile (Section 4.5.1). This approach identified a desired condition for groundwater return flows, and examined the volume of infiltration and total area of infiltration ponds required to achieve the target infiltration profile. The monthly infiltration profile was then run repeatedly through the SDF View analysis to evaluate return flow volumes over an extended period of time.

2. Water Supply in Excess of Entitlements and Flow Requirements (Excess Surface Storage) (Section 4.5.2). This approach used the historical monthly availability of TWSA for the period from 1978 to 2000 to determine which months there was water supply in reservoir storage in excess of entitlements and flow requirements that could be diverted into infiltration ponds. This time series of monthly infiltration volumes was then run through the SDF View analysis to evaluate return flow volumes from 1978 to 2000.

### 4.5.1 Target Return Flow Profile

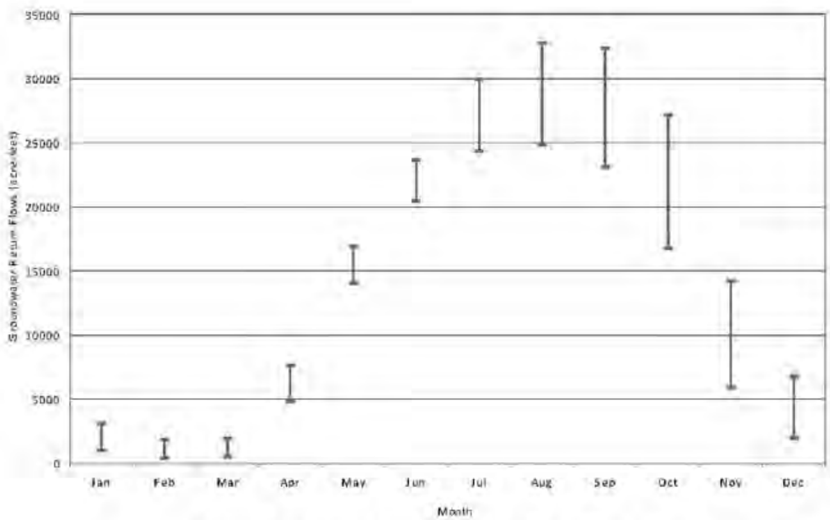
The U.S. Bureau of Reclamation’s RiverWare model estimates the groundwater return flows to the Yakima River above Parker gauge (Easton, Cle Elum, Umtanum, Naches) and below Parker gauge (Parker, Kiona). Monthly groundwater return flows were provided by reach based on the RiverWare model data from 1981 to 2004 (Sonnichson pers. comm., 2007). Figure 4-7 shows the range in monthly groundwater return flows from the RiverWare model above and below the Parker gauge. The target return flow volumes were estimated as the difference between the minimum and average groundwater return flow above and below the Parker gauge (Table 4-5; Figure 4-8). Achieving the target return profile would “normalize” the current groundwater return flows to a level that would be more consistent from year-to-year and would be, on average, higher than current levels. This would improve TWSA. The differences between currently modeled minimum and average groundwater return flow range from 2,000 to 8,000 AF per month, and the largest differences occur in September and October.

**TABLE 4-5**

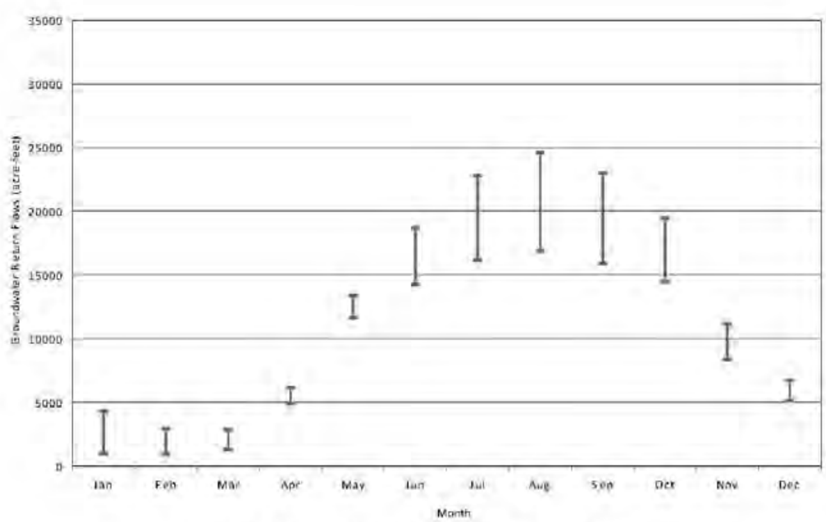
Target[1] Accretion Volumes Above and Below Parker Gauge

| Month | Above Parker Gauge (acre-feet) | Below Parker Gauge (acre-feet) |
|---|---|---|
| Jan[2] | 0 | 0 |
| Feb[2] | 0 | 0 |
| Mar[2] | 0 | 0 |
| Apr[2] | 0 | 0 |
| May[2] | 0 | 0 |
| Jun | 2,052 | 3,663 |
| Jul | 3,852 | 5,511 |
| Aug | 6,125 | 6,438 |
| Sep | 7,417 | 5,660 |
| Oct | 7,944 | 3,773 |
| Nov | 5,925 | 1,949 |
| Dec[2] | 0 | 0 |

Notes:
1. The "target" represents the difference between average and minimum groundwater return flow in the RiverWare model from 1981 to 2004.
2. Although there is a difference between the minimum and average groundwater return flow in the RiverWare model from December through May, these months were not targeted for streamflow augmentation.




Range in Monthly Groundwater Return Flows
Above Parker (1981-2004)

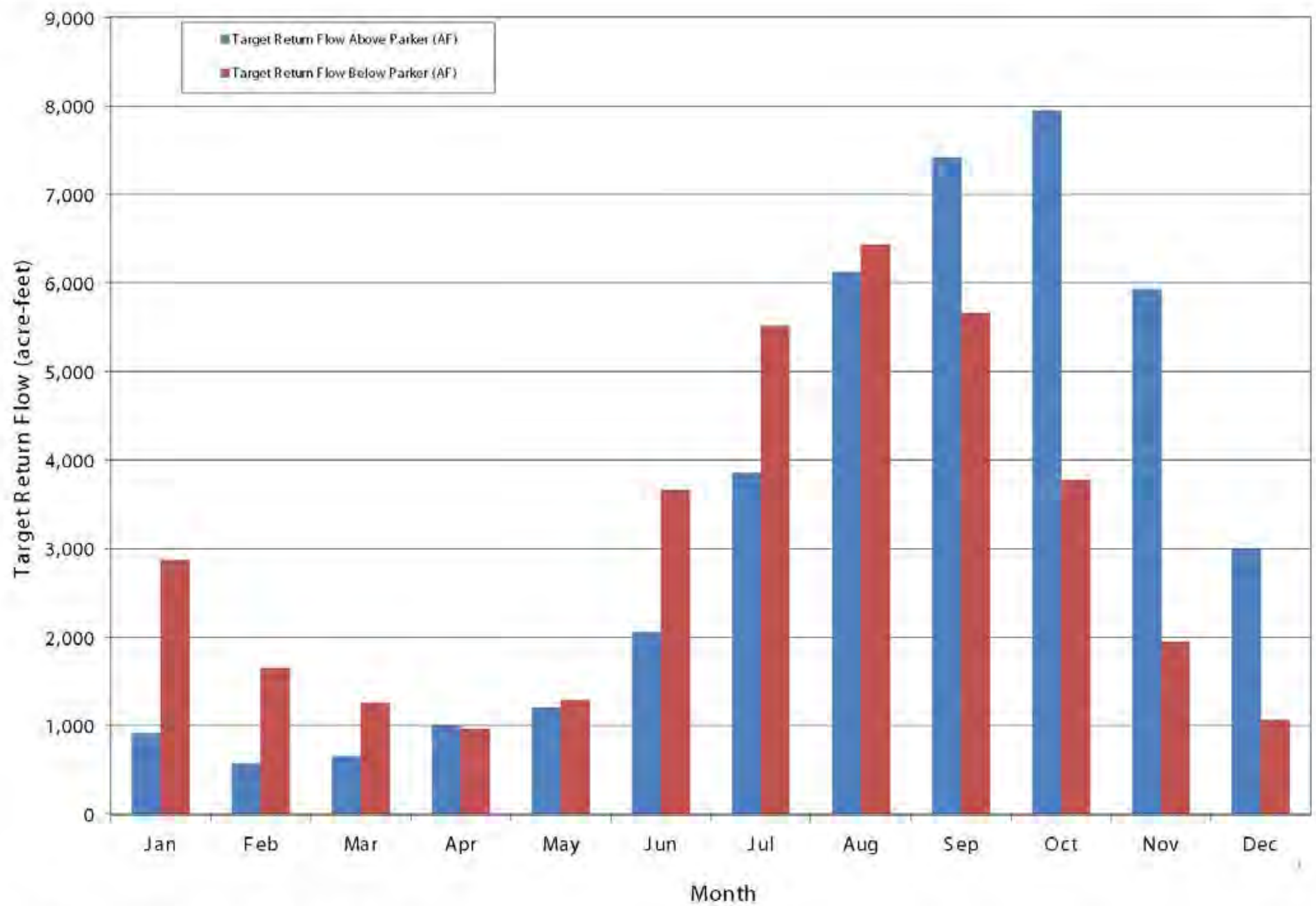



Range in Monthly Groundwater Return Flows
Below Parker gauge (1981-2004)

*Note: Data from Bureau of Reclamation RiverWare Model (Sonnichson, pers. comm., 2007)*

FIGURE **4-7**
**RANGE IN MONTHLY GROUNDWATER RETURN FLOWS (1981-2004)**
ANCHOR/YAKIMA RVR BASIN STORAGE/WA

**Golder Associates**




*Note. These volumes represent the difference between the minimum and average groundwater return flow from 1981 – 2004 using data from the Bureau of Reclamation's Riverware Model.*

FIGURE **4-8**
**TARGET ACCRETION VOLUMES ABOVE AND BELOW PARKER GAUGE**
ANCHOR/YAKIMA RVR BASIN STORAGE/WA

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The delivery volume needed to achieve the target return flow volume consists of the water that will infiltrate plus the water lost to evaporation while in the pond. The water lost to evaporation was calculated using the average monthly potential evaporation recorded at the Yakima WSO AP site from 1946 to 2005 multiplied by the acres of land that would be covered by ponds. The range in acreages that would be covered by ponds is provided in Table 4-6. The acreages are based on the infiltration rate, and maximum monthly volume of infiltration water needed to achieve the target. A low infiltration capacity combined with a high SDF value would require over 1,000 acres of land to achieve the target accretion volumes shown in Table 4-5. They would also require that infiltration occur during July and August on a regular basis.

Table 4-7 displays the range in monthly infiltration volumes necessary to achieve the monthly accretion target using a SDF of 30 and 60. The evaporation loss from the ponds ranges from one to four percent of the total delivery volume. The return flow volume in any given month is the sum of the accretion from all prior months of infiltration. For example, the return flow volume in September is the sum of the accretion from infiltration in May, June, July, and August (in addition to some year-to-year carry over). The decay of an individual month's infiltration is determined by the SDF factor, so the sum of the accretion from previous months is sensitive to the SDF factor. A pond with a SDF of 30 can achieve the target return flow profile with a fairly uniform delivery volume, while a pond with a SDF of 60 would have a more variable delivery volume. For example, the monthly infiltration volumes needed above Parker with a SDF of 30 range from 4,900 AF to almost 12,000 AF. However, the monthly infiltration volumes range from 0 AF to over 20,000 AF with a SDF of 60.

The monthly return flow volumes increase in response to year-after-year infiltration. This is because of the interannual storage capacity of the aquifer. Cumulative accretion profiles were developed using the same monthly infiltration volumes shown on Table 4-7 for five years. The results of the five-year analysis are provided in Appendix B.

The results of the first approach, the target return flow approach, indicate that to "normalize" groundwater return flows to a level that would be consistent from year-to-year requires delivery of significant amounts of water from the reservoirs during July and August. In many years, water needed for irrigation (both nonproratable and proratable) would have priority and there would not be enough water available to fully "normalize" the current groundwater return flow profile.

The second approach, the excess surface storage approach, evaluates the potential effects of surface recharge return flow volumes when the availability of water for infiltration ponds is constrained by the historical amount of excess surface storage.

**TABLE 4-6**

Total Acres Needed to Infiltrate the Total Infiltration Volume and Achieve the Accretion Target[1]

| Location | SDF (days) | Total Infiltration Volume (AF) | Maximum Year 1 Monthly Infiltration Volume (AF) | Total Acres of Land to Based on Different Pond Infiltration Capacities[2] | | |
|---|---|---|---|---|---|---|
| | | | | High | Medium | Low |
| Above Parker Gauge | 30 | 51,775 | 11,820 | 210 | 333 | 621 |
| | 40 | 54,750 | 13,980 | 248 | 393 | 734 |
| | 50 | 56,235 | 17,410 | 309 | 490 | 914 |
| | 60 | 63,960 | 23,435 | 416 | 660 | 1,231 |
| Below Parker Gauge | 30 | 37,582 | 11,545 | 205 | 325 | 606 |
| | 40 | 39,840 | 14,759 | 262 | 415 | 775 |
| | 50 | 43,419 | 18,622 | 331 | 524 | 978 |
| | 60 | 46,813 | 23,288 | 414 | 655 | 1,222 |

Notes:

1. The "target" represents the difference between average and minimum groundwater return flow in the RiverWare model from 1981 to 2004.
2. Refer to Table 4-2 for the pond infiltration capacity.

## TABLE 4-7

Range in Delivery Volumes Needed to Achieve a Target Accretion Volume

| Stream Depletion Factor (days) | Component | Delivery Month | | | | | | Total Year 1 Volume (acre-feet) |
|---|---|---|---|---|---|---|---|---|
| | | May (acre-feet) | June (acre-feet) | July (acre-feet) | August (acre-feet) | September (acre-feet) | October (acre-feet) | |
| Above Parker Gauge | | | | | | | | |
| 30 | Infiltration Volume[1] | 6,470 | 6,700 | 11,820 | 11,785 | 10,095 | 4,905 | 51,775 |
| | Evaporation[2] | 73 - 216 | 89 - 264 | 182 - 539 | 162 - 479 | 91 - 269 | 0 | 597 - 1,768 |
| | Delivery Volume[3] | 6,543 - 6,686 | 6,789 - 6,964 | 12,002 - 12,359 | 11,947 - 12,264 | 10,186 - 10,364 | 4,905 | 52,372 - 53,543 |
| 60 | Infiltration Volume[1] | 13,045 | 2,540 | 23,435 | 3,090 | 21,850 | 0 | 63,960 |
| | Evaporation[2] | 147 - 435 | 34 - 100 | 361 - 1,069 | 43 - 125 | 197 - 583 | 0 | 782 - 2,313 |
| | Delivery Volume[3] | 13,192 - 13,480 | 2,574 - 2,640 | 23,796 - 24,504 | 3,133 - 3,215 | 22,047 - 22,433 | 0 | 64,742 - 66,273 |
| *Range[4]* | | *6,543 - 13,480* | *2,574- 6,964* | *12,002 - 24,504* | *3,133 - 12,264* | *10,186 - 22,433* | *0 - 4,905* | *52,372 - 66,273* |
| Below Parker Gauge | | | | | | | | |
| 30 | Infiltration Volume[1] | 11,545 | 7,862 | 10,535 | 6,094 | 1,514 | 32 | 37,582 |
| | Evaporation[2] | 130 - 385 | 105 - 309 | 163 - 480 | 84 - 248 | 14 - 40 | 0 | 495 - 1,462 |
| | Delivery Volume[3] | 11,675 - 11,930 | 7,967 - 8,171 | 10,698 - 11,015 | 6,178 - 6,342 | 1,528 - 1,554 | 32 | 38,077 - 39,044 |

**TABLE 4-7 (continued)**

Range in Delivery Volumes Needed to Achieve a Target Accretion Volume

| Stream Depletion Factor (days) | Component | Delivery Month May (acre-feet) | June (acre-feet) | July (acre-feet) | August (acre-feet) | September (acre-feet) | October (acre-feet) | Total Year 1 Volume (acre-feet) |
|---|---|---|---|---|---|---|---|---|
| 60 | Infiltration Volume[1] | 23,288 | 0 | 22,250 | 0 | 1,275 | 0 | 46,813 |
| | Evaporation[2] | 263 - 776 | 0 | 343 - 1,014 | 0 | 12,754 | 0 | 618 - 1,824 |
| | Delivery Volume[3] | 23,551 - 24,064 | 0 | 22,593 - 23,264 | 0 | 1,287 - 1,309 | 0 | 47,431 - 48,637 |
| *Range[4]* | | *11,675 - 24,064* | *0 - 8,171* | *10,698 - 23,264* | *0 - 6,342* | *1,287 - 1,554* | *0 - 32* | *38,077 - 48,637* |

Notes:
1. The infiltration volume represents the volume of water that reaches the aquifer.
2. The evaporation was calculated using the average monthly potential evaporation recorded at the Yakima WSO AP site from 1946 to 2005 along with the acres of land that would be covered by ponds (see Table 4-4) (Western Regional Climate Center, 2007). The average monthly potential evaporation is 7.62 inches in May, 8.71 inches in June, 10.42 inches in July, 9.29 inches in August, and 5.90 inches in September. The site does not record evaporation in October, so 0 inches was used for October. The range represents the variability associated with the different infiltration rates. A higher infiltration rate will result in the water infiltrating faster, so less land area is needed (see Table 4-4). Less land area means that there is less water lost to evaporation.
3. The total delivery volume needed is the sum of the infiltration and evaporation volumes.
4. The range is based on the monthly volume of water needed using stream depletion factors of 30 and 60 days and a range in the infiltration rate at the site. Smaller stream depletion factors produce more accretion in the first couple of months, with less water for future months from one month of infiltration. Larger stream depletion factors produce less accretion in the first couple of months and more accretion in future months compared to smaller stream depletion factors from one month of infiltration.

### 4.5.2 Water Supply in Excess of Entitlements and Flow Requirements (Excess Surface Storage) Approach

The Reclamation Interim Comprehensive Basin Operating Plan for the Yakima Project, Washington contains a monthly historical summary of TWSA from 1978 to 2000 (see Table 3-3). This summary was used to calculate monthly volumes of “excess” surface storage that remained in reservoirs based on the TWSA operating protocol. Table 4-8 summarizes the monthly volumes of “excess” surface storage. The volumes of water shown on Table 4-8 are volumes in excess of the storage necessary to meet all entitlements (proratable and nonproratable) for all subsequent months in the year. It was assumed that between 10,000 and 20,000 AF of water could be released for surface recharge when excess surface storage exceeded 25,000 AF. The resulting time series of excess surface storage available for surface recharge is shown on Figure 4-9. In general, the release of 10,000 to 20,000 AF represents between one and thirty-five percent of the excess surface storage for that month. In many months, there is no excess surface storage, and no infiltration is assumed during that month (Table 4-9a).

The resulting return flow profiles are shown on Table 4-9b and Figure 4-10 (SDF = 30) and Table 4-9c and Figure 4-11 (SDF = 60). Each figure shows the entire 1978 to 2000 time series of monthly return flows from infiltration of 10,000 AF when it is available in excess of existing entitlements (Figures 4-10 and 4-11). The plot of the entire time series shows how the return flows decay and peak in relation to the monthly magnitude and timing of the infiltration. The figures also show the time series for each July and August and are described as follows:

- July: In most years, there is sufficient excess surface storage to infiltrate 10,000 AF/month during the early summer. An increase in July groundwater return flow of about 6,000 AF (100 cfs) is predicted for a SDF of 30 and 60. In five of those years (1978, 1982, 1988, 1989, and 1992), there is less excess storage available, and an increase in return flow of between 2,000 and 4,000 AF (33 to 67 cfs) is predicted. During drought years (1993, 1994), there is no excess storage available, but return flows of 450 to 650 AF (7.5 to 11 cfs) are predicted as a result of carry-over from previous years infiltration.

- August: The availability of excess storage to infiltrate 10,000 AF/month during July is a significant determinant of the predicted increase in August return flow. When there is sufficient excess storage to infiltrate 10,000 AF during all months leading up to July, an increase in return flow of between 6,500 and 7,500 AF (109 to 126 cfs) is predicted for a SDF of 30 and 60. In years where there is no excess storage to infiltrate during July (1978, 1982, 1987, 1992) an increase in August return flow of 3,500 and 4,500 AF (59 to 75 cfs) is predicted. During drought years (1993, 1994), there is no storage available, but return flows of 400 to 600 AF (6.7 to 10 cfs) are predicted as a result of carry-over from previous years of infiltration.

## TABLE 4-8

Monthly Volumes of Water Supply in Excess of Entitlements and Flow Requirements[1]

| Year | Month | | | | | |
|---|---|---|---|---|---|---|
| | **April** | **May** | **June** | **July** | **August** | **September** |
| 1978 | 368,530 | 286,360 | - | 233,850 | 178,690 | |
| 1979 | 347,530 | 405,360 | 324,460 | | | |
| 1980 | 837,530 | 650,360 | 481,460 | | | |
| 1981 | 57,530 | 241,360 | 339,460 | | | |
| 1982 | 946,530 | 950,360 | | | | |
| 1983 | 1,082,530 | 886,360 | 631,460 | | | |
| 1984 | 476,530 | 446,360 | 560,460 | | | |
| 1985 | 801,530 | 813,360 | 755,460 | 329,850 | 157,690 | |
| 1986 | 358,530 | 229,360 | 160,460 | 167,850 | | |
| 1987 | 249,530 | 242,360 | 21,460 | 101,850 | | |
| 1988 | | 10,360 | 70,460 | 149,850 | | |
| 1989 | 761,530 | 611,360 | 552,460 | | | |
| 1990 | 958,530 | 769,360 | 777,460 | 517,850 | | |
| 1991 | 652,530 | 687,360 | 621,460 | 654,850 | | |
| 1992 | 112,530 | 213,360 | | | 46,690 | |
| 1993 | | | | | 32,690 | 26,570 |
| 1994 | | | | | | 117,570 |
| 1995 | 704,778 | 581,608 | 424,658 | 349,048 | | |
| 1996 | 538,728 | 451,558 | 339,658 | 240,048 | | |
| 1997 | 2,196,828 | 1,745,658 | 994,758 | 700,148 | | |
| 1998 | 642,778 | 469,558 | 353,658 | 313,048 | | |
| 1999 | 1,852,828 | 1,558,658 | 1,341,758 | 678,148 | | |
| 2000 | 959,590 | 606,608 | 511,420 | 391,810 | | |

Notes:

1. Water supply in excess of entitlements and flow requirements represents the historical TWSA (Table 3-3) in excess of the accumulated entitlements (Table 3-4) and Title XII instream flows needs (Table 3-2).

**TABLE 4-9a**

Assumed Delivery of Water for Surface Recharge under the Water Supply in Excess of Entitlements and Flow Requirements Approach

| Year | January (acre-feet) | February (acre-feet) | March (acre-feet) | April (acre-feet) | May (acre-feet) | June (acre-feet) | July (acre-feet) | August (acre-feet) | September (acre-feet) | October (acre-feet) | November (acre-feet) | December (acre-feet) | Total Annual (acre-feet) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1978 | 0 | 0 | 0 | 0 | 10,000 | 10,000 | 0 | 10,000 | 10,000 | 0 | 0 | 0 | 40,000 |
| 1979 | 0 | 0 | 0 | 0 | 10,000 | 10,000 | 10,000 | 0 | 0 | 0 | 0 | 0 | 30,000 |
| 1980 | 0 | 0 | 0 | 0 | 10,000 | 10,000 | 10,000 | 0 | 0 | 0 | 0 | 0 | 30,000 |
| 1981 | 0 | 0 | 0 | 0 | 10,000 | 10,000 | 10,000 | 0 | 0 | 0 | 0 | 0 | 30,000 |
| 1982 | 0 | 0 | 0 | 0 | 10,000 | 10,000 | 0 | 0 | 0 | 0 | 0 | 0 | 20,000 |
| 1983 | 0 | 0 | 0 | 0 | 10,000 | 10,000 | 10,000 | 0 | 0 | 0 | 0 | 0 | 30,000 |
| 1984 | 0 | 0 | 0 | 0 | 10,000 | 10,000 | 10,000 | 0 | 0 | 0 | 0 | 0 | 30,000 |
| 1985 | 0 | 0 | 0 | 0 | 10,000 | 10,000 | 10,000 | 10,000 | 10,000 | 0 | 0 | 0 | 50,000 |
| 1986 | 0 | 0 | 0 | 0 | 10,000 | 10,000 | 10,000 | 10,000 | 0 | 0 | 0 | 0 | 40,000 |
| 1987 | 0 | 0 | 0 | 0 | 10,000 | 10,000 | 0 | 10,000 | 0 | 0 | 0 | 0 | 30,000 |
| 1988 | 0 | 0 | 0 | 0 | 0 | 0 | 10,000 | 10,000 | 0 | 0 | 0 | 0 | 20,000 |
| 1989 | 0 | 0 | 0 | 0 | 10,000 | 10,000 | 10,000 | 0 | 0 | 0 | 0 | 0 | 30,000 |
| 1990 | 0 | 0 | 0 | 0 | 10,000 | 10,000 | 10,000 | 10,000 | 0 | 0 | 0 | 0 | 40,000 |
| 1991 | 0 | 0 | 0 | 0 | 10,000 | 10,000 | 10,000 | 10,000 | 0 | 0 | 0 | 0 | 40,000 |
| 1992 | 0 | 0 | 0 | 0 | 10,000 | 10,000 | 0 | 0 | 10,000 | 0 | 0 | 0 | 30,000 |
| 1993 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10,000 | 10,000 | 0 | 0 | 20,000 |
| 1994 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10,000 | 0 | 0 | 10,000 |
| 1995 | 0 | 0 | 0 | 0 | 10,000 | 10,000 | 10,000 | 10,000 | 0 | 0 | 0 | 0 | 40,000 |
| 1996 | 0 | 0 | 0 | 0 | 10,000 | 10,000 | 10,000 | 10,000 | 0 | 0 | 0 | 0 | 40,000 |
| 1997 | 0 | 0 | 0 | 0 | 10,000 | 10,000 | 10,000 | 10,000 | 0 | 0 | 0 | 0 | 40,000 |
| 1998 | 0 | 0 | 0 | 0 | 10,000 | 10,000 | 10,000 | 10,000 | 0 | 0 | 0 | 0 | 40,000 |
| 1999 | 0 | 0 | 0 | 0 | 10,000 | 10,000 | 10,000 | 10,000 | 0 | 0 | 0 | 0 | 40,000 |
| 2000 | 0 | 0 | 0 | 0 | 10,000 | 10,000 | 10,000 | 10,000 | 0 | 0 | - | - | 40,000 |

Note:
1. Assumed 10,000 AF delivery of water for surface recharge when monthly excess (Table 4-8) is greater than 20,000 AF.

## TABLE 4-9b

SDF 30 Monthly Cumulative Accretion Profile under the Water Supply in Excess of Entitlements and Flow Requirements Approach

| Year | January (acre-feet) | February (acre-feet) | March (acre-feet) | April (acre-feet) | May (acre-feet) | June (acre-feet) | July (acre-feet) | August (acre-feet) | September (acre-feet) | October (acre-feet) | November (acre-feet) | December (acre-feet) | Total Annual (acre-feet) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1978 | 0 | 0 | 0 | 0 | 3,329 | 5,524 | 3,416 | 4,743 | 6,338 | 3,993 | 1,794 | 1,181 | 30,318 |
| 1979 | 845 | 592 | 530 | 424 | 3,700 | 5,832 | 7,024 | 4,052 | 1,894 | 1,278 | 909 | 738 | 27,817 |
| 1980 | 602 | 476 | 440 | 372 | 3,671 | 5,820 | 7,022 | 4,058 | 1,905 | 1,294 | 927 | 758 | 27,344 |
| 1981 | 624 | 481 | 465 | 397 | 3,695 | 5,843 | 7,047 | 4,082 | 1,928 | 1,317 | 949 | 780 | 27,608 |
| 1982 | 646 | 501 | 486 | 417 | 3,716 | 5,863 | 3,737 | 1,709 | 1,078 | 831 | 644 | 557 | 20,182 |
| 1983 | 479 | 382 | 380 | 333 | 3,643 | 5,804 | 7,014 | 4,056 | 1,909 | 1,301 | 937 | 772 | 27,009 |
| 1984 | 640 | 514 | 482 | 415 | 3,715 | 5,864 | 7,068 | 4,104 | 1,951 | 1,340 | 971 | 804 | 27,868 |
| 1985 | 670 | 522 | 510 | 440 | 3,740 | 5,886 | 7,090 | 7,454 | 7,493 | 4,775 | 2,369 | 1,669 | 42,616 |
| 1986 | 1,262 | 925 | 863 | 718 | 3,980 | 6,084 | 7,268 | 7,610 | 4,454 | 2,393 | 1,589 | 1,260 | 38,408 |
| 1987 | 1,022 | 784 | 756 | 646 | 3,927 | 6,048 | 3,913 | 5,200 | 3,575 | 1,882 | 1,264 | 1,018 | 30,034 |
| 1988 | 839 | 675 | 636 | 550 | 515 | 457 | 3,765 | 6,126 | 3,585 | 1,770 | 1,139 | 895 | 20,952 |
| 1989 | 727 | 562 | 547 | 473 | 3,773 | 5,917 | 7,122 | 4,157 | 2,001 | 1,391 | 1,020 | 854 | 28,544 |
| 1990 | 719 | 566 | 558 | 485 | 3,786 | 5,930 | 7,135 | 7,498 | 4,362 | 2,312 | 1,521 | 1,198 | 36,070 |
| 1991 | 968 | 742 | 715 | 611 | 3,896 | 6,022 | 7,218 | 7,571 | 4,425 | 2,370 | 1,573 | 1,247 | 37,358 |
| 1992 | 1,013 | 805 | 750 | 644 | 3,928 | 6,051 | 3,917 | 1,877 | 4,404 | 3,487 | 1,670 | 1,205 | 29,749 |
| 1993 | 944 | 716 | 689 | 591 | 550 | 486 | 463 | 430 | 3,562 | 6,213 | 3,584 | 1,760 | 19,988 |
| 1994 | 1,161 | 802 | 729 | 600 | 543 | 471 | 442 | 406 | 365 | 3,682 | 2,672 | 1,224 | 13,098 |
| 1995 | 802 | 561 | 518 | 434 | 3,729 | 5,876 | 7,081 | 7,448 | 4,317 | 2,268 | 1,482 | 1,161 | 35,679 |
| 1996 | 935 | 737 | 683 | 583 | 3,870 | 5,999 | 7,196 | 7,551 | 4,407 | 2,354 | 1,558 | 1,233 | 37,105 |
| 1997 | 1,000 | 768 | 742 | 636 | 3,920 | 6,044 | 7,240 | 7,592 | 4,445 | 2,390 | 1,591 | 1,265 | 37,635 |
| 1998 | 1,031 | 795 | 770 | 662 | 3,946 | 6,067 | 7,263 | 7,614 | 4,465 | 2,410 | 1,610 | 1,284 | 37,917 |

**TABLE 4-9b**

SDF 30 Monthly Cumulative Accretion Profile under the Water Supply in Excess of Entitlements and Flow Requirements Approach

| Year | January (acre-feet) | February (acre-feet) | March (acre-feet) | April (acre-feet) | May (acre-feet) | June (acre-feet) | July (acre-feet) | August (acre-feet) | September (acre-feet) | October (acre-feet) | November (acre-feet) | December (acre-feet) | Total Annual (acre-feet) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1999 | 1,049 | 810 | 787 | 678 | 3,961 | 6,082 | 7,277 | 7,628 | 4,479 | 2,423 | 1,622 | 1,297 | 38,094 |
| 2000 | 1,061 | 849 | 795 | 686 | 3,970 | 6,091 | 7,286 | 7,638 | 4,487 | 2,432 | - | - | 35,296 |
| Average (acre-feet) | 828 | 633 | 601 | 513 | 3,370 | 5,220 | 5,826 | 5,244 | 3,558 | 2,431 | 1,518 | 1,098 | 30,726 |
| Average (cfs) | 13 | 11 | 10 | 9 | 55 | 88 | 95 | 85 | 60 | 40 | 26 | 18 | 43 |

Note:

SDF View cumulative accretion model results from the infiltration profile in Table 4-8 using a SDF of 30.

**TABLE 4-9c**

SDF 60 Monthly Cumulative Accretion Profile under the Water Supply in Excess of Entitlements and Flow Requirements Approach

| Year | January (acre-feet) | February (acre-feet) | March (acre-feet) | April (acre-feet) | May (acre-feet) | June (acre-feet) | July (acre-feet) | August (acre-feet) | September (acre-feet) | October (acre-feet) | November (acre-feet) | December (acre-feet) | Total Annual (acre-feet) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1978 | 0 | 0 | 0 | 0 | 1,709 | 4,057 | 3,752 | 3,497 | 5,126 | 4,523 | 2,303 | 1,566 | 26,533 |
| 1979 | 1,138 | 804 | 724 | 582 | 2,219 | 4,483 | 5,847 | 4,663 | 2,444 | 1,701 | 1,228 | 1,006 | 26,840 |
| 1980 | 826 | 656 | 607 | 516 | 2,183 | 4,469 | 5,846 | 4,673 | 2,461 | 1,724 | 1,254 | 1,035 | 26,248 |
| 1981 | 857 | 664 | 643 | 550 | 2,218 | 4,502 | 5,880 | 4,707 | 2,494 | 1,757 | 1,285 | 1,066 | 26,622 |
| 1982 | 888 | 691 | 673 | 578 | 2,246 | 4,530 | 4,199 | 2,200 | 1,437 | 1,126 | 880 | 766 | 20,214 |
| 1983 | 662 | 530 | 528 | 463 | 2,147 | 4,448 | 5,836 | 4,672 | 2,467 | 1,736 | 1,269 | 1,054 | 25,813 |
| 1984 | 880 | 710 | 667 | 576 | 2,246 | 4,531 | 5,911 | 4,739 | 2,525 | 1,790 | 1,317 | 1,100 | 26,992 |
| 1985 | 922 | 722 | 707 | 611 | 2,280 | 4,562 | 5,941 | 6,476 | 6,608 | 5,567 | 3,085 | 2,235 | 39,717 |
| 1986 | 1,715 | 1,267 | 1,188 | 992 | 2,611 | 4,836 | 6,188 | 6,693 | 5,222 | 3,121 | 2,133 | 1,713 | 37,678 |
| 1987 | 1,401 | 1,080 | 1,046 | 896 | 2,541 | 4,788 | 4,444 | 4,135 | 4,126 | 2,455 | 1,700 | 1,388 | 30,001 |
| 1988 | 1,154 | 933 | 881 | 765 | 718 | 637 | 2,318 | 4,809 | 4,079 | 2,287 | 1,523 | 1,216 | 21,320 |
| 1989 | 998 | 776 | 758 | 658 | 2,327 | 4,607 | 5,987 | 4,813 | 2,596 | 1,862 | 1,386 | 1,170 | 27,937 |
| 1990 | 991 | 783 | 774 | 675 | 2,346 | 4,625 | 6,005 | 6,539 | 5,095 | 3,008 | 2,039 | 1,628 | 34,508 |
| 1991 | 1,327 | 1,022 | 989 | 848 | 2,497 | 4,751 | 6,120 | 6,640 | 5,183 | 3,090 | 2,110 | 1,696 | 36,274 |
| 1992 | 1,390 | 1,110 | 1,038 | 893 | 2,541 | 4,792 | 4,450 | 2,434 | 3,224 | 3,956 | 2,178 | 1,623 | 29,631 |
| 1993 | 1,290 | 986 | 954 | 820 | 766 | 677 | 646 | 600 | 2,117 | 4,858 | 4,073 | 2,272 | 20,059 |
| 1994 | 1,553 | 1,090 | 1,000 | 828 | 753 | 655 | 616 | 567 | 511 | 2,203 | 2,935 | 1,572 | 14,283 |
| 1995 | 1,075 | 765 | 713 | 601 | 2,265 | 4,548 | 5,930 | 6,469 | 5,032 | 2,948 | 1,985 | 1,577 | 33,908 |
| 1996 | 1,280 | 1,015 | 945 | 809 | 2,461 | 4,719 | 6,089 | 6,612 | 5,158 | 3,066 | 2,090 | 1,677 | 35,921 |

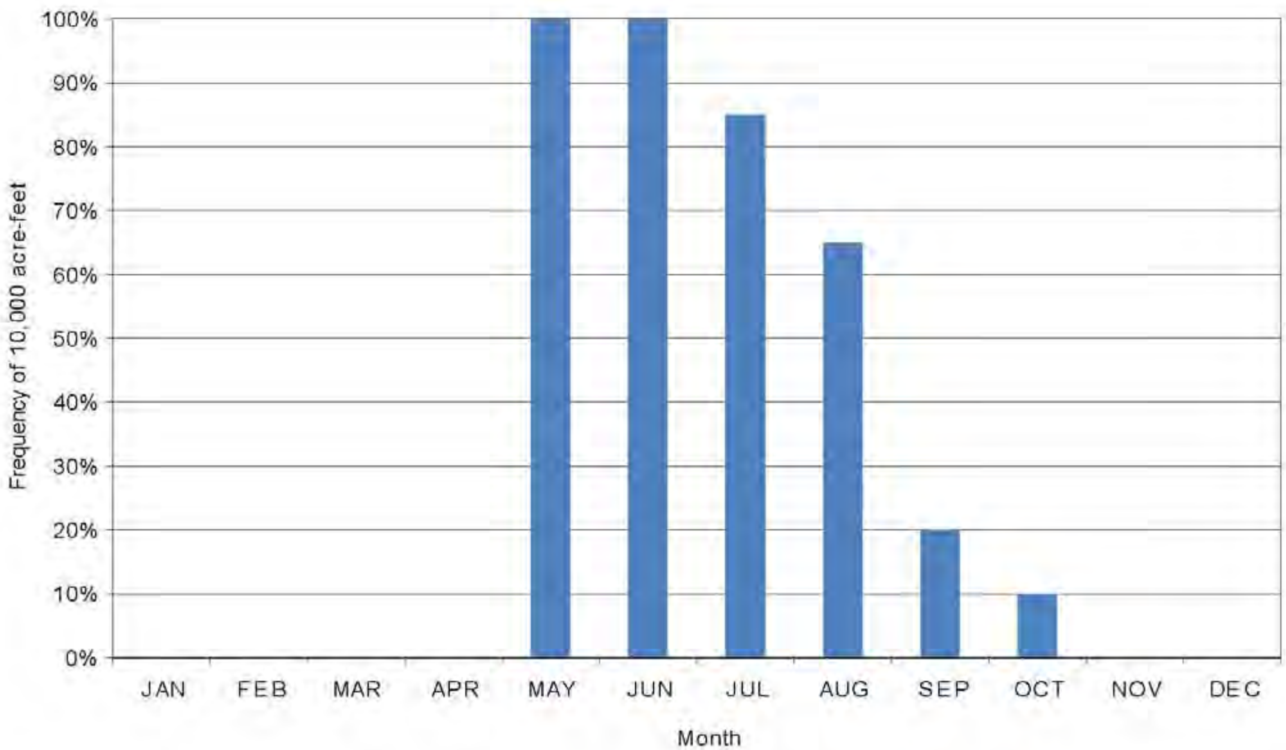
**TABLE 4-9c**

SDF 60 Monthly Cumulative Accretion Profile under the Water Supply in Excess of Entitlements and Flow Requirements Approach

| Year | January (acre-feet) | February (acre-feet) | March (acre-feet) | April (acre-feet) | May (acre-feet) | June (acre-feet) | July (acre-feet) | August (acre-feet) | September (acre-feet) | October (acre-feet) | November (acre-feet) | December (acre-feet) | Total Annual (acre-feet) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1997 | 1,372 | 1,059 | 1,027 | 883 | 2,531 | 4,783 | 6,151 | 6,670 | 5,211 | 3,117 | 2,136 | 1,722 | 36,662 |
| 1998 | 1,415 | 1,096 | 1,066 | 919 | 2,567 | 4,815 | 6,183 | 6,701 | 5,239 | 3,146 | 2,163 | 1,748 | 37,058 |
| 1999 | 1,440 | 1,118 | 1,090 | 941 | 2,589 | 4,836 | 6,204 | 6,721 | 5,258 | 3,165 | 2,180 | 1,766 | 37,308 |
| 2000 | 1,457 | 1,171 | 1,102 | 953 | 2,602 | 4,848 | 6,216 | 6,734 | 5,270 | 3,177 | - | - | 33,531 |
| Average (acre-feet) | 1,132 | 872 | 831 | 711 | 2,146 | 4,109 | 5,077 | 4,903 | 3,865 | 2,843 | 1,966 | 1,482 | 29,785 |
| Average (cfs) | 18 | 16 | 14 | 12 | 35 | 69 | 83 | 80 | 65 | 46 | 33 | 24 | 41 |

Note:

SDF View cumulative accretion model results from the infiltration profile in Table 4-8 using a SDF of 60.




*Note: Figure shows frequency that 10,000 AF was available over the period 1978-2000. Availability was based on USBR's monthly TWSA calculations summarized on Table 3-3.*

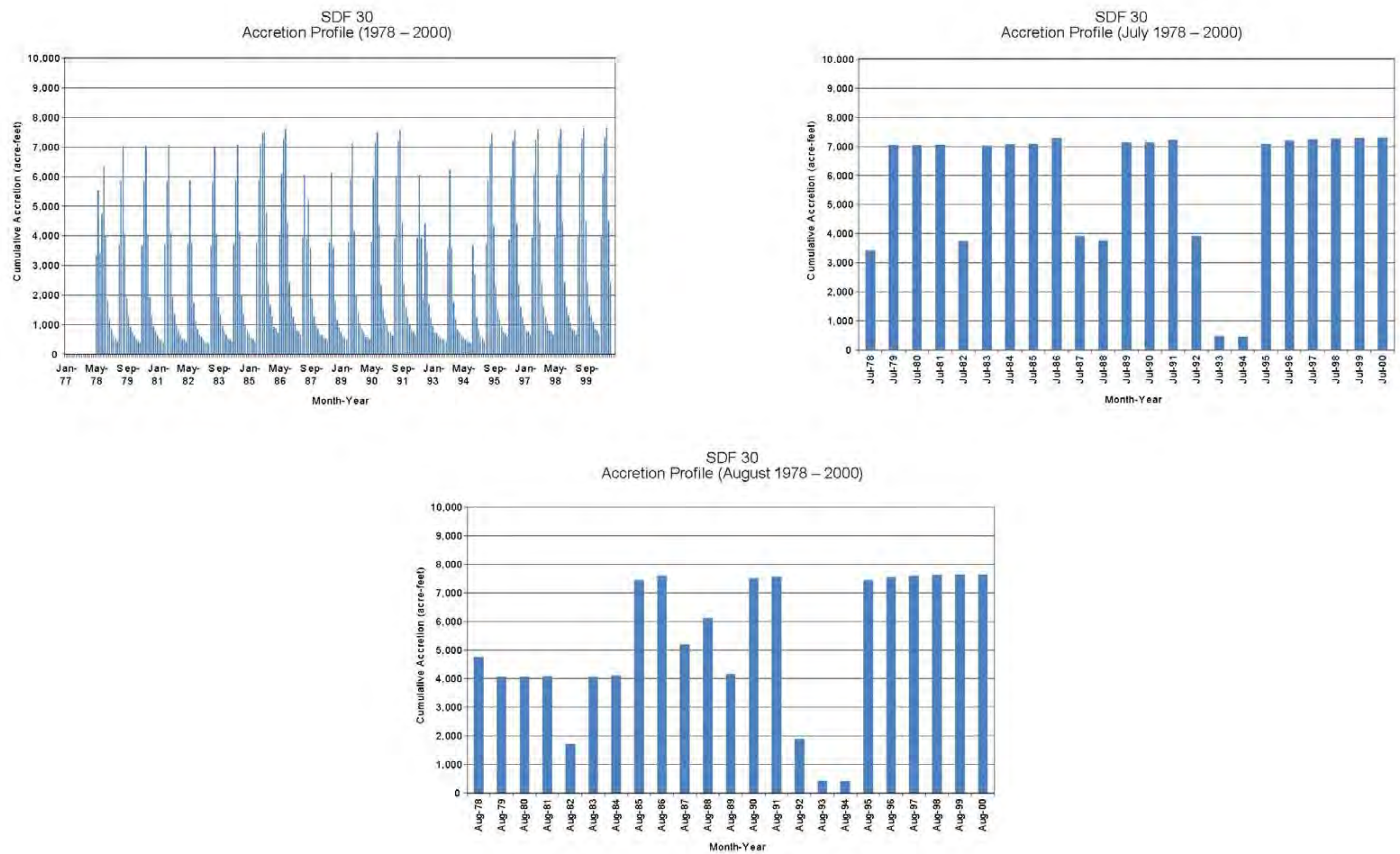
FIGURE **4-9**

**AVAILABILITY OF WATER SUPPLY IN EXCESS OF ENTITLEMENTS AND FLOW REQUIREMENTS FOR SURFACE RECHARGE**

ANCHOR/YAKIMA RVR BASIN STORAGE/WA

07393277120fig4-9.ai | Mod: 10/15/07 | AMP

**Golder Associates**




*Note: Accretion based on infiltration of 10,000 AF per month, when available over remaining entitlements. SDF 30 relates to the time lag for return flow. SDF30 has a faster return flow compared to SDF 60.*

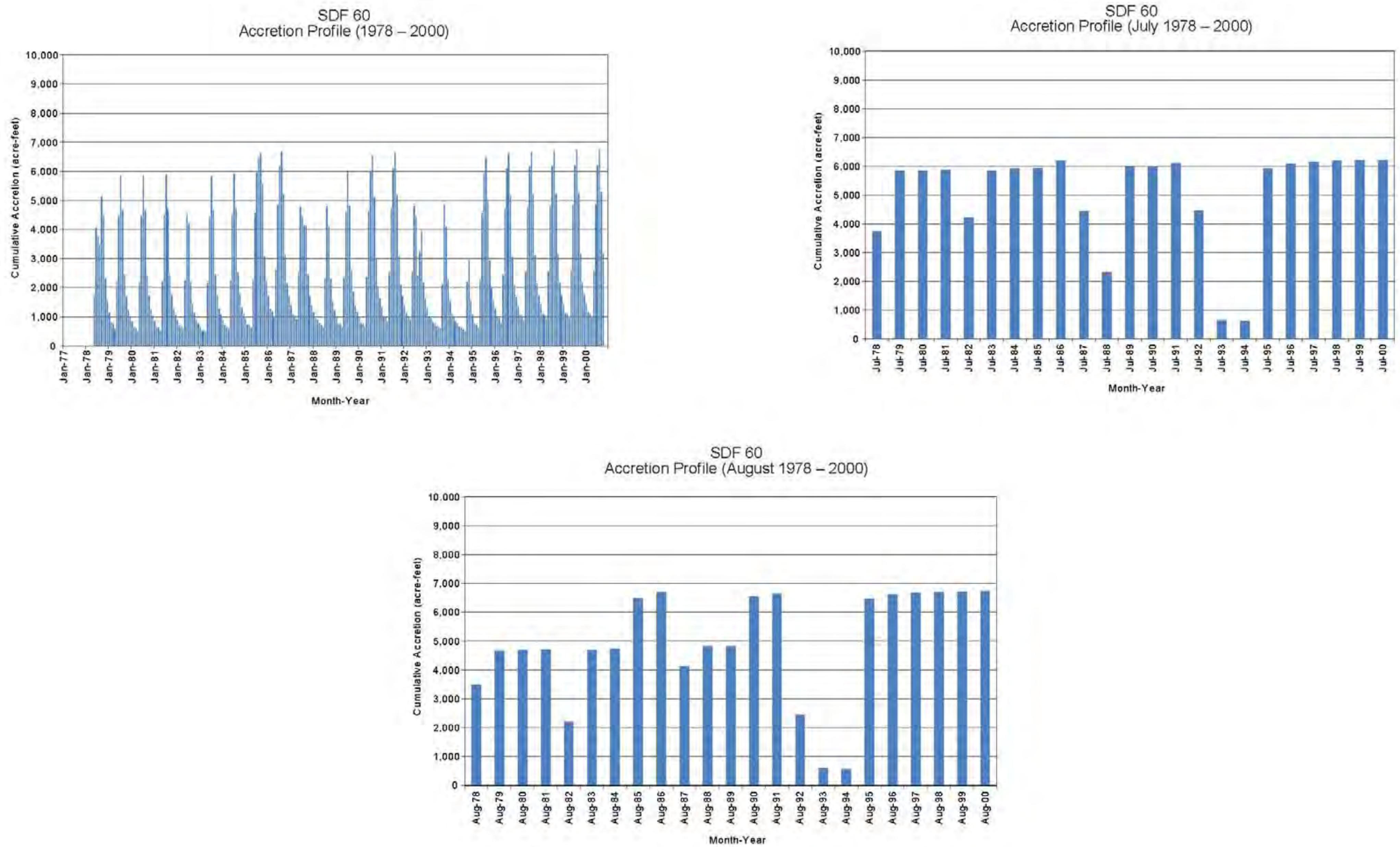
FIGURE **4-10**

**CUMULATIVE ACCRETION PROFILE USING THE WATER SUPPLY IN EXCESS OF ENTITLEMENTS AND FLOW REQUIREMENTS APPROACH AND A SDF OF 30**

ANCHOR/YAKIMA RVR BASIN STORAGE/WA

**Golder Associates**

07393277120fig4-10.ai | Mod: 10/16/07 | AMP




*Note: Accretion based on infiltration of 10,000 AF per month, when available over remaining entitlements. SDF 60 relates to the time lag for return flow. SDF 60 has a slower return flow compared to SDF 30.*

FIGURE **4-11**

**CUMULATIVE ACCRETION PROFILE USING THE WATER SUPPLY IN EXCESS OF ENTITLEMENTS AND FLOW REQUIREMENTS APPROACH AND A SDF OF 60**

ANCHOR/YAKIMA RVR BASIN STORAGE/WA

07393277120fig4-11.ai | Mod: 10/16/07 | AMP

**Golder Associates**

The streamflow improvements from surface recharge as a percent of the historical monthly flows at Umtanum gauge were estimated. Figure 4-12 shows observed flows at Umtanum gauge and the estimated percent increase in streamflows from surface recharge. In terms of streamflow improvements, the return flow estimates suggest that infiltration of 10,000 AF/month during months when there is excess TWSA will result in average and maximum August streamflow improvements of 2.3 to 5.2 percent at Umtanum gauge,. The average streamflow improvement in August is expected to range from 4,903 to 5,244 acre-feet (80 to 85 cfs), depending on the SDF value at the site. Streamflow improvements of up to 12 and 15 percent are predicted for drought years (1993) in October. This represents approximately 4,900 to 6,200 AF (80 to 100 cfs) of return flow from surface recharge. If 20,000 AF/month were infiltrated during months when there is excess TWSA, August streamflow improvements of 4.7 to 9.6 percent are predicted. This represents approximately 10,100 to 14,400 AF (170 to 240 cfs) of return flow from surface recharge. Under a 20,000 AF scenario, streamflow improvements of 6 to 28 percent are predicted for drought years (1993) in September and October, depending on the relative proportion of areas with a SDF value of 30 or 60. This represents approximately 5,700 to 11,000 AF (95 to 185 cfs) of return flow from surface recharge.

## 4.6 WATER QUALITY

Surface recharge using canal water that is similar in water quality to the storage reservoirs will tend to shift the alluvial groundwater geochemistry towards the canal water type. Water quality data for seepage discharge at Moxee Drain are summarized on Table 4-10. This water quality is assumed to be representative of shallow groundwater in the unconfined aquifer and has a slightly alkaline pH and an average temperature of 15.8 degrees Celsius. Nitrate concentrations are between 2 and 6 milligrams per liter (mg/L). Metal concentrations are low, ranging from several to tens of parts per billion. Water quality of the Yakima River at Cle Elum is assumed to be representative of water quality in the major canals, particularly in the upper reaches of the basin. Dissolved ions and temperature are much lower compared to the Moxee Drain water quality. Infiltration of this cool high quality water in controlled surface recharge basins is expected to improve water quality in the groundwater return flow. Significant geochemical interactions between applied surface recharge and the unconfined aquifer are not anticipated.

## 4.7 COSTS

The costs associated with surface recharge sites will be highly variable depending on the location and design of the infiltration facilities. Rather than conduct a detailed engineering cost breakdown, a corollary approach was used to estimate costs for surface recharge. Construction cost data for the five CAP recharge facilities in Arizona were averaged and used to establish an average unit cost (per acre of infiltration facility). The CAP facilities include a variety of construction methods and designs, and the facilities are similar in size and capacity to the facilities that might be applicable to the Yakima River Basin. Therefore, the average costs should be representative. An inflation adjustment of 6 percent was added to account for the variations in when the facilities were constructed (1998 to 2004).

The average construction cost per acre for the CAP sites is $175,000. This average per acre cost produced approximately 200 acres of infiltration area at the CAP facilities in Arizona with a peak monthly infiltration capacity of 14,630 AF per month.

For the Yakima River Basin, total land area could range between 166 and 500 acres for similar infiltration capacities, with an expected area of about 300 acres. Based on the assumptions summarized on Table 4-11, total construction costs could range from $54M to $164M, with an expected cost of $98M. Assuming that surface recharge would divert and deliver a total of about 33,000 AF annually for groundwater storage, the annual cost per AF for groundwater storage is estimated to be in the range of between $1,646 to $4,958 per AF, with an expected value of $2,975 per AF.

Operation and maintenance (O&M) costs are difficult to estimate without more detailed estimates on facility designs. The CAP project in Arizona includes a fixed O&M cost of 73 $/AF (Cooke, 2004). These costs include about 62$/AF for pumping costs (2005 dollars). Although pumping costs are likely to be lower in the Yakima system, an estimated fixed O&M cost of 65 $/AF was assumed. Using these figures, annual O&M costs are estimated to be about $2.1M per year.

**TABLE 4-10**

General Surface Water and Groundwater Quality for Surface Recharge

| Water Quality | | EPA Drinking Water Standards [1] EPA-816-F-02-013 | Type [(a)] | Surface Water: Drainage Water [2] | Surface Water: Yakima River [2] | Groundwater: Unconfined Aquifer [2] |
|---|---|---|---|---|---|---|
| Location | | | | Moxee Drain | Cle Elum | Moxee |
| Formation | | | | - | - | Alluvium |
| Parameter | Units | | | | | |
| pH | s.u. | 6.5-8.5 | II | 7.7 to 8.6 | 6.7 to 7.6 | 6.81 to 8.16 |
| Temperature | °C | | | average 15.8 varying seasonally | 7.3 | 10.7 to 17.7 varying seasonally |
| TDS | mg/L | | | - | - | 200-690 |
| TSS | mg/L | | | - | - | - |
| Major Anions/Cations | | | | | | |
| F | mg/L | 4.0/2.0 | I/II | 0.4 to 0.8 | - | - |
| Cl | mg/L | 250 | II | 10 to 21 | 3 | 5 to 75 |
| $SO_4$ | mg/L | 250 | II | 27 to 60 | 2.6 | - |
| Ca | mg/L | | | 28 to 49 | 8.5 | - |
| Na | mg/L | | | 46 to 104 | 2.9 | - |
| K | mg/L | | | 3 to 5.4 | 0.8 | - |
| Mg | mg/L | | | 12 to 24 | 1.3 | - |
| Nutrients | | | | | | |
| $NO_3$ | mg/L-N | | | 2.1 to 5.9 | 0.09 | usually non-detect but occasionally spikes as high as 18.2 |
| DOC | mg/L | | | 3.7 to 38 | - | 1 to 4.4 |
| TOC | mg/L | | | - | - | - |
| Metals | | | | | | |
| Total Al | | | | - | - | - |
| Dissolved Al | mg/L | 0.05 to 0.2 | II | 0.004 to 0.008 | - | - |
| Total Fe | mg/L | | | - | - | 0.05 to 1.3 |
| Dissolved Fe | mg/L | 0.3 | II | 0.016 | - | - |
| Total Mn | | | | - | - | 0.01 to 0.5 |
| Dissolved Mn | mg/L | 0.05 | II | 0.009 to 0.017 | - | - |
| Redox | | | | | | |
| DO | mg/L | | | 9.7 to 12.2 | - | more reducing than surface water |
| Disinfection Byproducts | | | | | | |
| THM | mg/L | 0.08 | | - | - | - |
| HAA | mg/L | 0.06 | | - | - | - |

**Notes:**

(a) Primary (I) or secondary (II) maximum contaminant level (MCL).

"-" indicates the parameter was not included in the analysis.

**Source:**

1 EPA, 2002. List of Drinking Water Contaminants and MCLs. EPA 816-F-02-013, July 2002.

2 U.S. Geological Survey (USGS): Water Quality Data. http://waterdata.usgs.gov/nwis

**TABLE 4-11**

Estimated Costs of Surface Recharge Sites

| Component | | Range in Costs | | |
|---|---|---|---|---|
| | | Low | Expected | High |
| $/acre | Unit Construction Cost | $ 175,000 | $ 175,000 | $ 175,000 |
| $/acre | Land Acquisition | $ 12,000 | $ 12,000 | $ 12,000 |
| | Total Acres[1] | 166 | 300 | 500 |
| | | | | |
| | Construction Costs | $ 31,042,000 | $56,100,000 | $ 93,500,000 |
| | | | | |
| 15% | Permitting | $ 4,656,300 | $ 8,415,000 | $ 14,025,000 |
| 30% | Engineering Design | $ 9,312,600 | $ 16,830,000 | $ 28,050,000 |
| 30% | Contingency | $ 9,312,600 | $ 16,830,000 | $ 28,050,000 |
| | | | | |
| | **TOTAL CONSTRUCTION** | **$ 54,323,500** | **$ 98,175,000** | **$ 163,625,000** |
| | | | | |
| | Water Delivered (AF)[2] | 33,000 | 33,000 | 33,000 |
| | | | | |
| | Unit Costs ($/AF) | $ 1,646 | $ 2,975 | $ 4,958 |
| | | | | |
| $ 65 | **Fixed O&M (Annual Cost)** | **$ 2,145,000** | **$ 2,145,000** | **$ 2,145,000** |

Notes:

AF = acre-foot

1. Based on a maximum monthly infiltration volume of 10,000 AF.
2. The estimated water delivered is described in Table 4-9a.

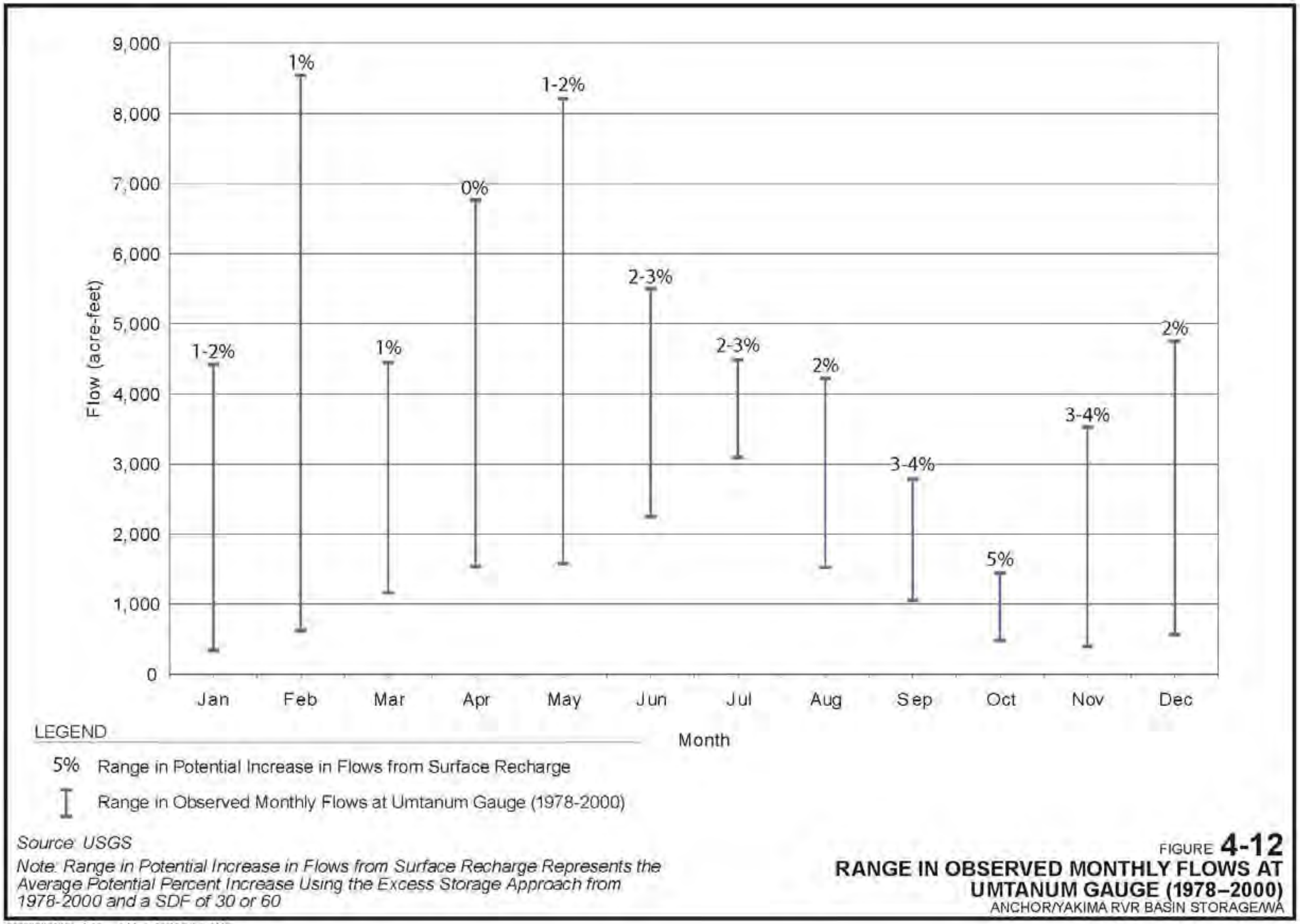



FIGURE 4-12
RANGE IN OBSERVED MONTHLY FLOWS AT UMTANUM GAUGE (1978–2000)

# 5.0 DIRECT INJECTION

One means of developing groundwater storage is to directly injecting water through wells into an aquifer. When the recharged groundwater is subsequently recovered by pumping the water back out (i.e., **active recovery**), the process is called Aquifer Storage and Recovery (ASR). The purpose of ASR is to store water when it is available (e.g., during the rainy season or high stream flow periods) using a natural underground storage reservoir (an aquifer), and then pump the stored water back out of the aquifer during time of higher demand (e.g., during the summer). The widest application of ASR is for municipal use, although it is used for other applications such as industrial uses.

Other applications of direct injection can replenish depleted aquifers or increase the seepage of groundwater back to streams. These applications are termed direct injection groundwater recharge with **passive recovery** because the stored water is not recovered by actively pumping the stored water back out of the aquifer.

## 5.1 CANDIDATE DIRECT INJECTION SITES

The objectives of direct injection within the Yakima Basin are to:

- Replace direct surface water diversions and groundwater withdrawals that have direct or seasonally significant impacts on streamflows

- Replace groundwater withdrawals that may otherwise have a longer-term impact on streamflows

- Provide for future water demands with minimal or no impact to streamflows

- Mitigate impacts from future water demand by augmenting streamflow

Identified candidates that may benefit from direct injection include the cities of Yakima (Ahtanum Valley), Ellensburg (Kittitas Valley), Kennewick (Lower Valley), the Blackrock-Moxee Valley and in the Lower Yakima Valley immediately downstream of Union Gap. Because the Ahtanum, Kittitas, and Blackrock-Moxee areas are upstream of the Parker gauge where the TWSA is established, the potential for the use of groundwater storage through direct injection at these sites are developed in detail (Figure 5-1). The other sites are addressed in lesser detail.

It is appropriate to focus efforts on population centers because the principal purpose of ASR is for municipal use. The largest population center in the Yakima Valley is the city of Yakima, located in the middle of the valley. The city of Yakima accounts for approximately 50 percent of the valley population that is located in incorporated areas (OFM, 2007). The primary municipal supply source for the city of Yakima is direct diversion of surface water from the Naches River under contract from the Bureau of Reclamation and state-issued water rights. Most of this diversion is subject to prorationing in water-short years. The city of Yakima has been prorationed during water-short years, and has had to issue water use restrictions to its customers. An ASR system for the city of Yakima would provide TWSA benefits to the system for two reasons:

- Although permitted under contract with the Bureau of Reclamation and associated water rights, the diversion of surface water has a direct impact on streamflows. Shifting to ASR during the summer would increase streamflows over what would otherwise occur under normal system operations.
- The supply of municipal water supply from this source is vulnerable to interruption in water-short years, thereby reducing the reliability of water supply for municipal use. Shifting to ASR would improve the protection of public health and safety and lessen the impacts of prorationing to all junior water right holders.

The city of Ellensburg is located in the Upper Valley and is the second largest population center in the Yakima Valley (OFM, 2007). State-issued groundwater rights to the city of Ellensburg have not been subject to interruption. The primary aquifer in this area is the Upper Ellensburg Formation. The application of ASR could offset potential impacts that current and future groundwater withdrawals may have on streamflows and thereby provide TWSA benefits to the system.

Groundwater in the Blackrock-Moxee area has been used for irrigation use since the early 1900s. Groundwater wells were "flowing artesian" initially, but groundwater levels have dropped in some areas by several hundred feet since the mid-1900s as a result of pumping and very low natural recharge. The primary aquifer in this area is basalt. Therefore, direct injection is being considered in this area to replenish groundwater storage and to partially restore streamflow that has resulted from decreased groundwater levels.

Direct injection of water at the headwaters of the Lower Yakima Valley (i.e., immediately below the Parker gage) is being considered to offset the small municipal users throughout the Lower Valley. Water recharged to the Upper Ellensburg Formation by direct injection could be passively recovered by seepage back to streams. Such seepage could be used to mitigate impacts from junior water users by increasing streamflows.

The city of Kennewick is partially located in the Lower Valley at the confluence of the Yakima River with the Columbia River and has a population of approximately 62,520 people (OFM, 2007). The city primarily obtains all of its water from the Columbia River. The geological setting being considered for ASR for the city of Kennewick is uniquely different from that for the cities of Ellensburg and Yakima. The target aquifers for ASR in the Ahtanum and Kittitas valleys are units of the Upper Ellensburg Formation with groundwater temperatures between $60^{o}$ F and $70^{o}$ F, and are moderately oxidizing. The target aquifer for ASR being considered by the city of Kennewick is basalt that is geothermally-influenced (groundwater temperatures on the order of $85^{o}$ F) and is highly reducing (i.e., the groundwater contains significant concentrations iron, manganese, and hydrogen sulfide).

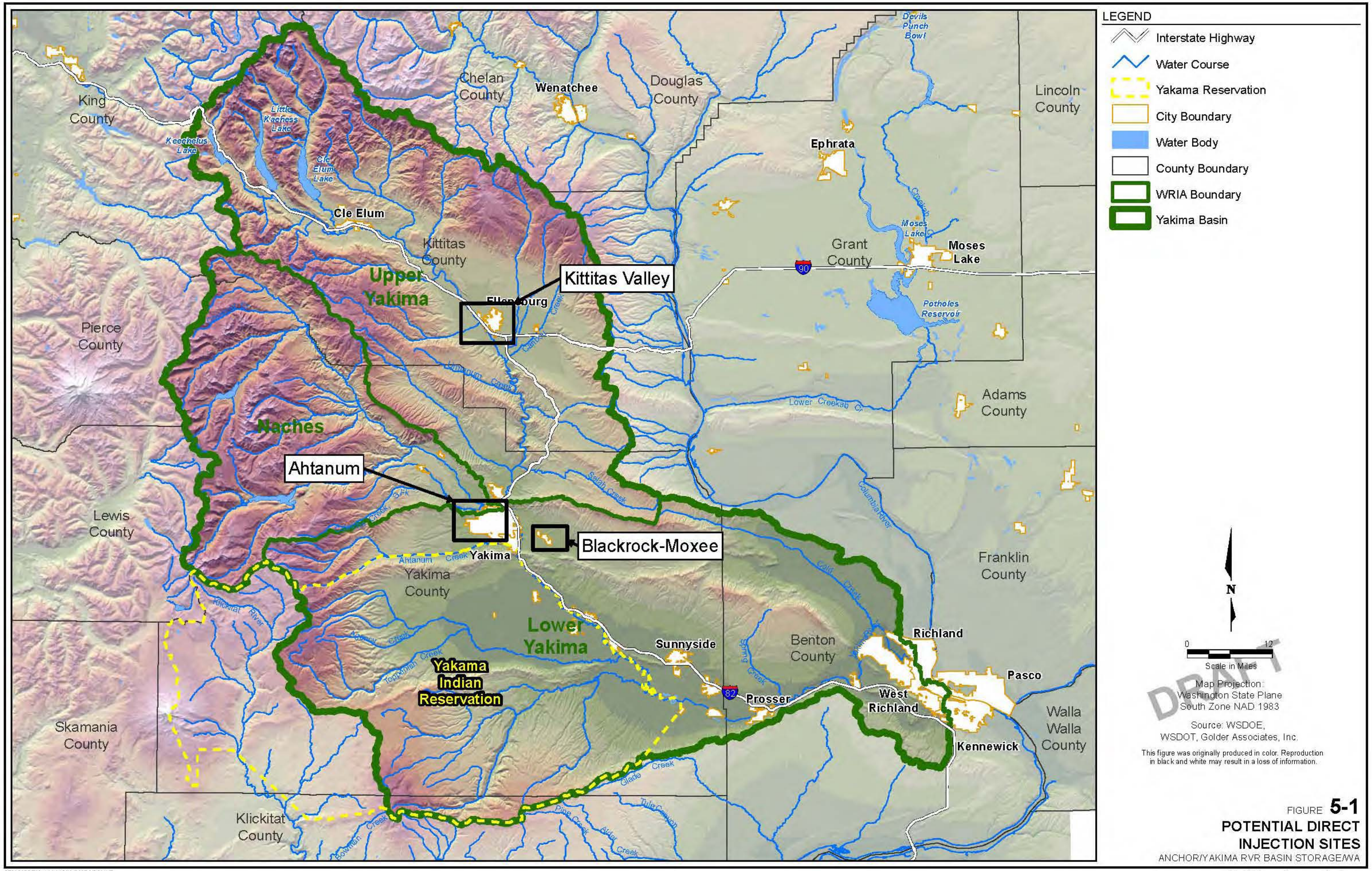



FIGURE 5-1
POTENTIAL DIRECT INJECTION SITES
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Geochemical considerations were evaluated for the application of ASR in geothermally-influenced reducing basalts for potable purposes because an ASR program in such a setting is being considered by the city of Kennewick, and may be implemented in similar settings (i.e., geothermally-influenced basalt aquifers) elsewhere in the Yakima Valley.

Groundwater storage by direct injection was quantitatively analyzed using a numerical simulation model of direct injection in the Ahtanum Valley. This numerical evaluation was then applied by extrapolation to the Kittitas and Lower valleys. Aquifer hydraulic properties were used to estimate the potential for groundwater storage in the Blackrock-Moxee area (i.e., piezometric head differences combined with aquifer storativity and aquifer area, or specific storage and aquifer volume).

## 5.2 MODELING DIRECT INJECTION – AHTANUM MOXEE SUB-BASIN

A three-dimensional groundwater flow model was used for the Ahtanum-Moxee Sub-basin in the Yakima Valley to evaluate the potential for using Aquifer Storage and Recovery (ASR) as a groundwater management option. The goal of the model was to estimate the quantity of recharged water to three injection wells that would (a) return to the Yakima River, (b) discharge at other hydrologic sinks, and (c) remain in the subsurface in the form of increased groundwater storage. The focus of the model was on seepage return flows to the Yakima River that result from direct injection to the deeper portions of the Ellensburg Formation. An analysis of active recovery was based on the increased aquifer storage.

The model was based on an earlier model (Golder, 2002) and uses essentially the same domain, hydrostratigraphic sequence, boundary conditions and hydraulic properties as the earlier model. This earlier model was developed for the Yakima Basin Watershed Planning Unit, and the model development, calibration, and application was documented in a report prepared by Golder for the planning unit (Golder, 2002). The original model used the US Geological Survey code MODFLOW-2000 (Harbargh et al, 2000) to simulate flow conditions, and the software program Groundwater Vistas (Rumbaugh and Rumbaugh, 1999) to facilitate operating the model.

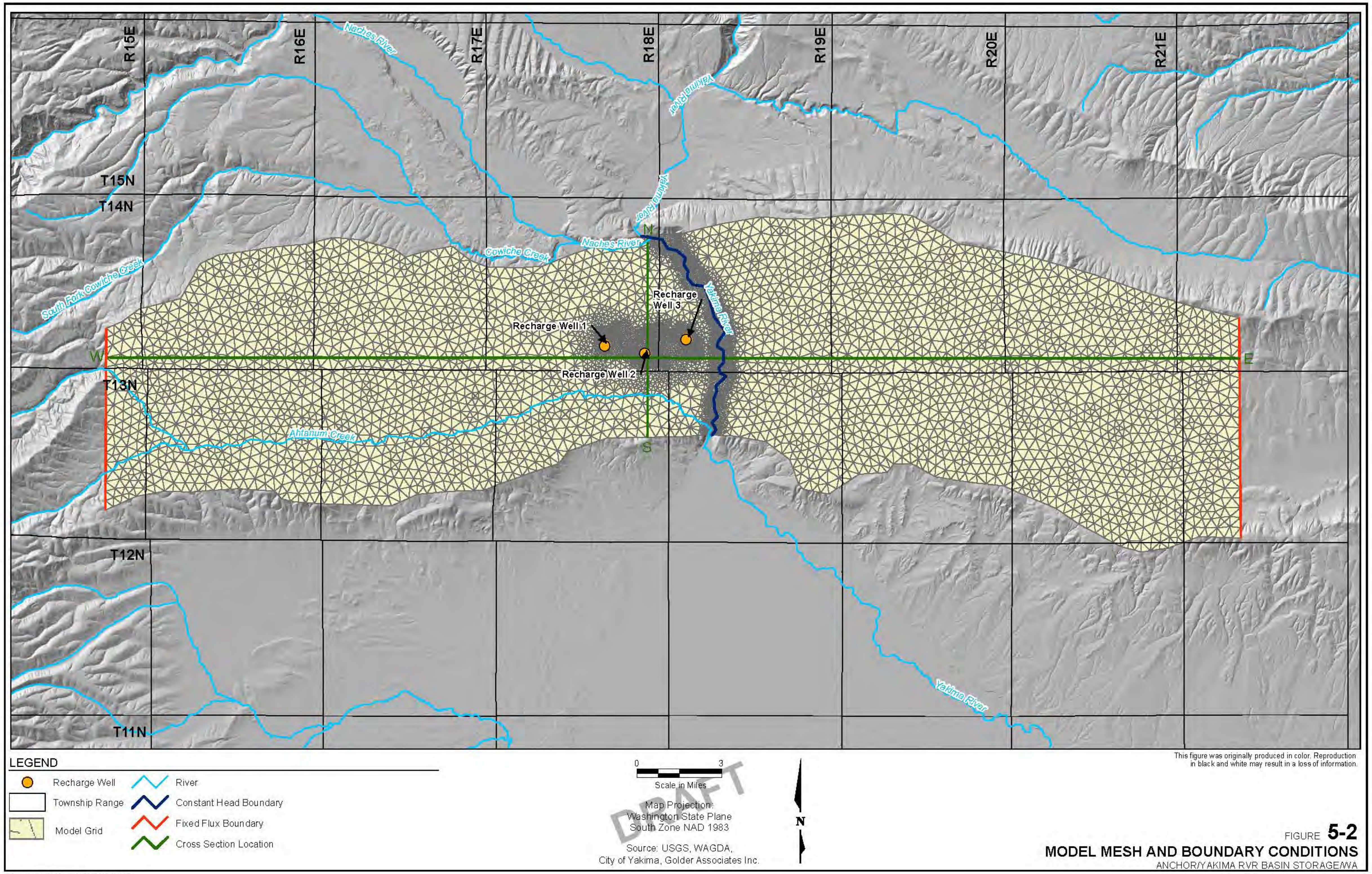
Some problems existed with the model. The most notable problem was that several areas towards the south and east of the model exhibited anomalously high water levels long after the recharge phase of the ASR simulation had been completed.

To overcome the difficulties associated with the MODFLOW model, the model was converted to the finite-element code FEFLOW (WASY, 1991). FEFLOW uses the finite-element method to solve the complex flow equations, and allows more flexibility in defining the model mesh than that offered by MODFLOW. FEFLOW also has a more robust approach to representing steeply-dipping layers and partially-saturated elements that exist in the Ahtanum sub-basin and are necessary for adequately representing the local groundwater flow regime.

### 5.2.1 Model Set-Up and Calibration

**Model Layering:** The FEFLOW model was constructed by developing a mesh of elements with a high concentration of small elements (with a minimum size of 50 feet) at the three recharge wells and the Yakima River and a largest element size (1,500 feet) near the model perimeter (Figure 5-2). Seven model layers were assigned (and eight slices, which represent the layer surfaces) for the model (Figures 5-3 and 5-4). The main structural matrix file sets were then exported from the original MODFLOW model and reinterpreting these to a new mesh. A new surface file was created for land surface using a 30-meter DEM file provided by the USGS.

**Modeled Hydraulic Properties:** The distribution of layer properties was generally the same as in the MODFLOW model. The major exception was the revision of the properties in model layers 1 through 6 outside the central area to be basalt (rather than weathered basalt). The simulated aquifer properties are presented in Table 5-1.


R15E
R16E
R17E
R18E
R19E
R20E
R21E
T15N
T14N
T13N
T12N
T11N
Naches River
Yakima River
Cowiche Creek
South Fork Cowiche Creek
Ahtanum Creek
Recharge Well 1
Recharge Well 2
Recharge Well 3
N
S
W
E
LEGEND
Recharge Well
Township Range
Model Grid
River
Constant Head Boundary
Fixed Flux Boundary
Cross Section Location
0 3
Scale in Miles
DRAFT
Map Projection:
Washington State Plane
South Zone NAD 1983
Source: USGS, WAGDA,
City of Yakima, Golder Associates Inc.
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This figure was originally produced in color. Reproduction in black and white may result in a loss of information.
FIGURE 5-2
MODEL MESH AND BOUNDARY CONDITIONS
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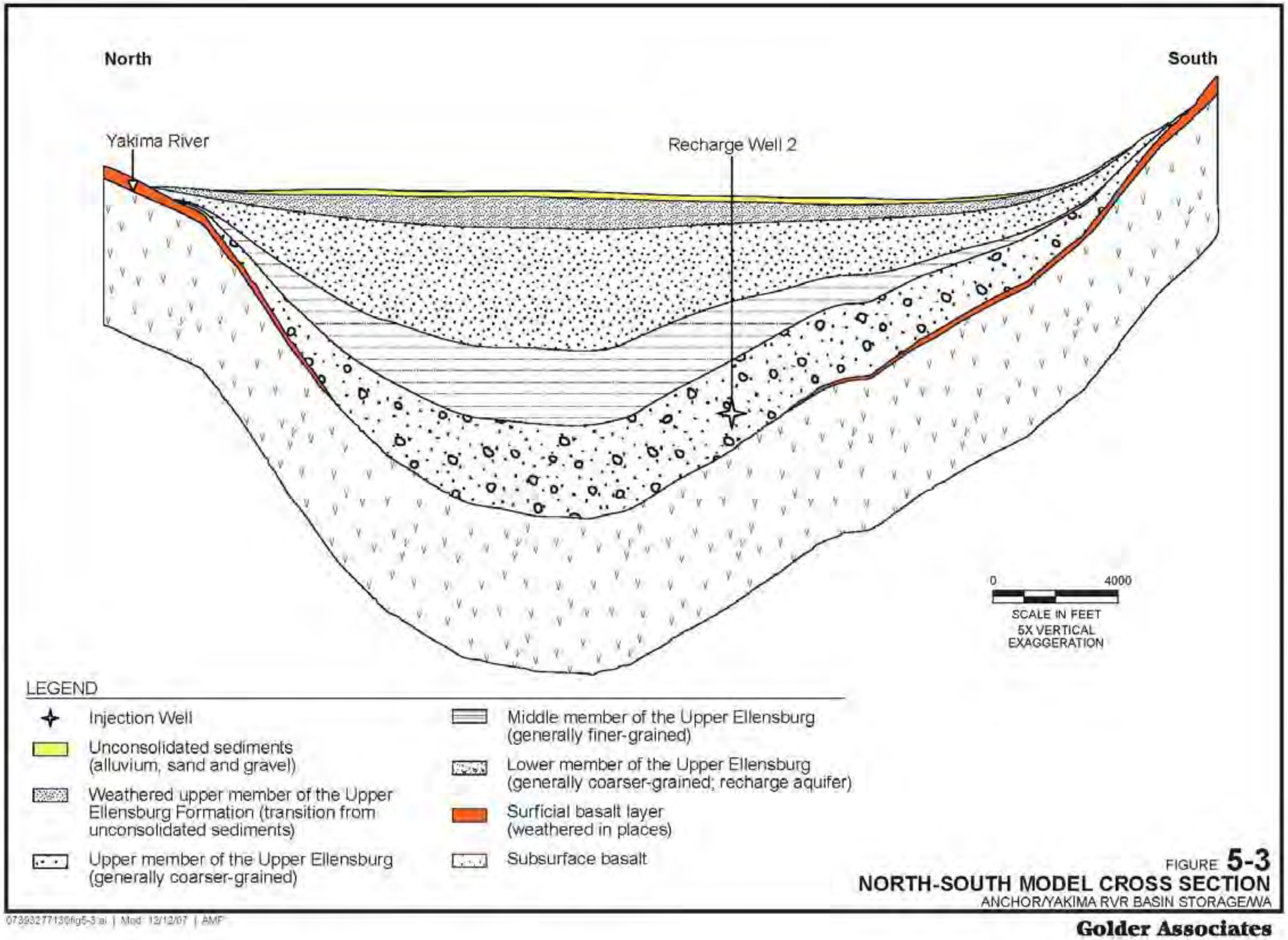
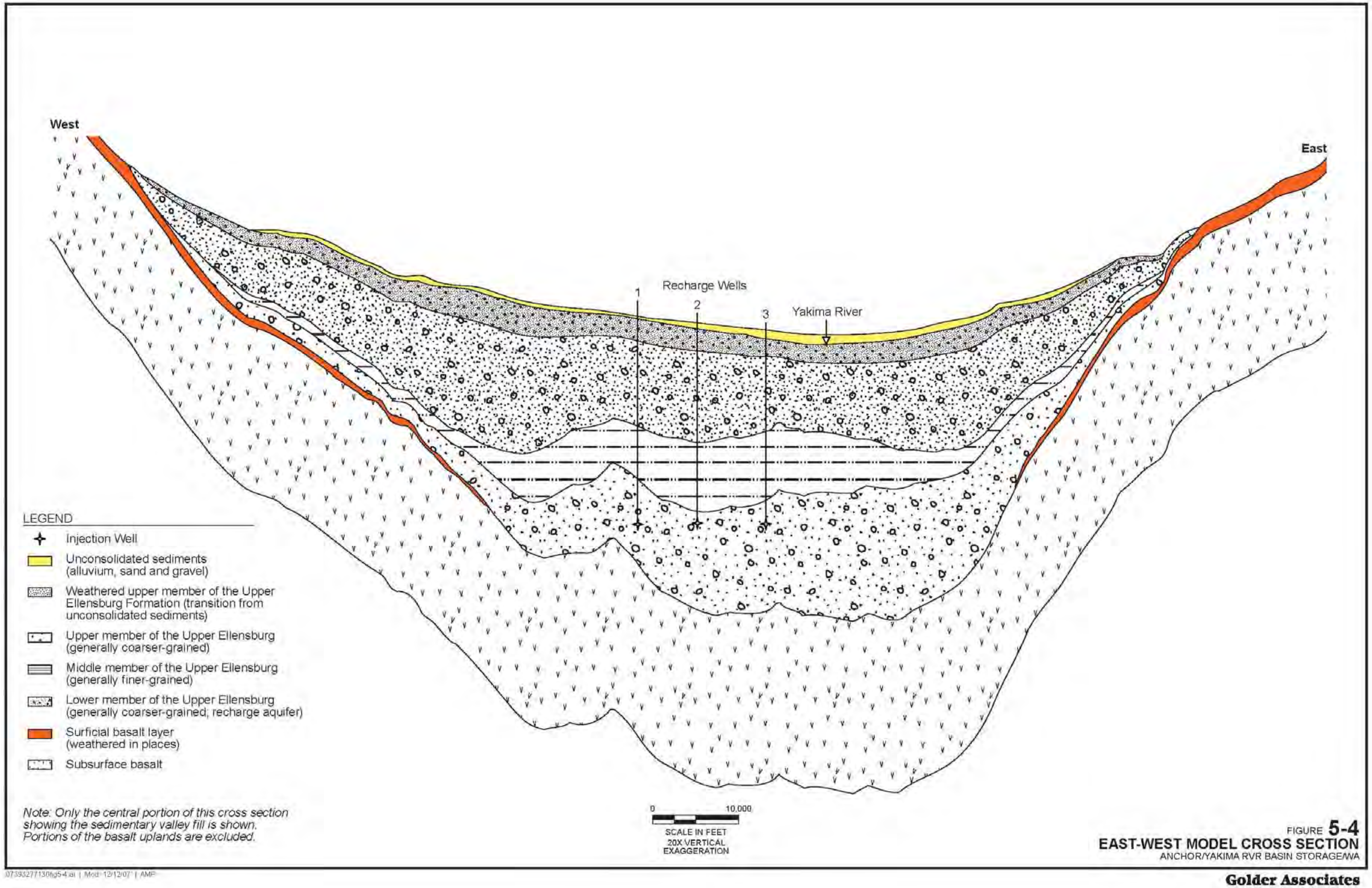



FIGURE 5-3
NORTH-SOUTH MODEL CROSS SECTION



West
East
Recharge Wells
1
2
3
Yakima River
LEGEND
Injection Well
Unconsolidated sediments (alluvium, sand and gravel)
Weathered upper member of the Upper Ellensburg Formation (transition from unconsolidated sediments)
Upper member of the Upper Ellensburg (generally coarser-grained)
Middle member of the Upper Ellensburg (generally finer-grained)
Lower member of the Upper Ellensburg (generally coarser-grained; recharge aquifer)
Surficial basalt layer (weathered in places)
Subsurface basalt
Note: Only the central portion of this cross section showing the sedimentary valley fill is shown. Portions of the basalt uplands are excluded.
0
10,000
SCALE IN FEET
20X VERTICAL EXAGGERATION
FIGURE 5-4
EAST-WEST MODEL CROSS SECTION
ANCHOR/YAKIMA RVR BASIN STORAGE/WA
Golder Associates

**TABLE 5-1**
Simulated Aquifer Properties for ASR Evaluation

| Model Layer | Hydrostratigraphic Unit | Thickness (ft) | $K_h$ (ft/d) | $K_v$ (ft/d) | Storativity | Specific Yield |
|---|---|---|---|---|---|---|
| 1 | Alluvium | 1 – 80 | 284 | 28.4 | 0.1 | 0.2 |
| 2 | Transition Zone – Alluvium/Upper Ellensburg (upper) | 1 – 200 | 75 | 7.5 | 0.007 | 0.06 |
| 3 | Upper Ellensburg (upper) | 3 – 800 | 7.5 | 0.75 | 0.0007 | 0.06 |
| 4 | Upper Ellensburg (middle) | 5 – 500 | 0.05 | 0.0005 | 0.0001 | 0.06 |
| 5 | Upper Ellensburg (lower) | 5 – 800 | 7.5 | 0.75 | 0.0007 | 0.06 |
| | | | 0.1 | 0.01 | 0.0007 | 0.06 |
| | | | 0.03 | 0.003 | 0.0007 | 0.06 |
| 6 | Weathered basalt | 20 | 0.003 | 0.0003 | 0.0001 | 0.02 |
| 7 | Basalt | 1,000 | 5 | 0.5 | 0.0001 | 0.06 |

Notes
$K_h$ – horizontal hydraulic conductivity;
$K_v$ – vertical hydraulic conductivity.

**Model Boundary Conditions:** The assigned FEFLOW model boundary conditions are the same as in the MODFLOW model, and are as follows:

1. Subsurface Inflow – was represented using fixed fluxes:

    a. Eastern Boundary – 6,700 ac-ft/yr (average seepage rate of 12 gallons per minute (gpm) per 100 linear feet).

    b. Western Boundary – 1,675 ac-ft/yr (average seepage rate of 3 gpm per 100 linear feet).

    These inflow fluxes were simulated using a line of constant flux (Type 1) conditions in model layer 7 only, with a uniform distribution along each line.

2. Yakima River – was represented using a constant head condition in model layer 1 (Alluvium), with the river heads ranging from 1,080 feet mean sea level (msl) at the northern edge of the model to 950 feet msl at the southern boundary. These heads were assigned based on approximate average river stage levels from the USGS topographic map.

3. Direct Aerial Recharge – was assumed to equal to recharge derived from precipitation and was calculated on an average annual basis. The rates and geographic distribution was the same as in the MODFLOW model, and ranged from 0.2 inches per year (in/yr) in the central part of the sub-basin to 9.5 in/yr near the northwestern boundary.

**Model Calibration:**

The purpose of calibration was to ensure that the model reproduces observed conditions as closely as possible. A steady-state calibration was performed primarily using a set of 177 water-level measurements made in wells located throughout the domain and screened in the Upper Ellensburg Formation (layer 3; 45 wells), the Lower Ellensburg formation (layer 5; 17 wells) and the basalt (layer 7; 115 wells). The water levels, well locations, and well elevations were based on the driller's logs produced at the time of well construction for more than 30 years. For the purposes of a comparative evaluation of water balances under ASR scenarios, the dataset is considered reasonable, though there are accuracy limitations with this dataset.

Observed and simulated groundwater levels in layer 3 (the upper member of the Upper Ellensburg Formation) are shown in Figure 5-5. The calibration results are summarized in Figure 5-6, which shows the graphical distribution of modeled versus observed water levels for the three layers (3, 5 and 7), and the overall statistical results. The root-mean square error is 6.2 percent for 177 wells. These results are reasonable because of the relatively large range in observed values in the model (1,631 feet). The modeled discharge to the Yakima River was 37.7 cfs. The northern river reach is simulated as a losing reach (that is, water discharges from the river to the shallow alluvium), whereas the central and southern reaches are gaining reaches (shallow groundwater discharges to the river). The overall model water budget is shown in Table 5-2.

**<u>TABLE 5-2</u>**

**Calibrated Model Water Budget**
(cfs)

| Component | Inflow | Outflow | Net |
|---|---|---|---|
| Precipitation-derived Recharge | +18.9 | 0 | +18.9 |
| Wells | 0 | 0 | 0 |
| Subsurface Flow | +18.8 | 0 | +18.8 |
| Rivers | +4.9 | -42.6 | - 37.7 |
| Totals | +42.6 | -42.6 | 0 |

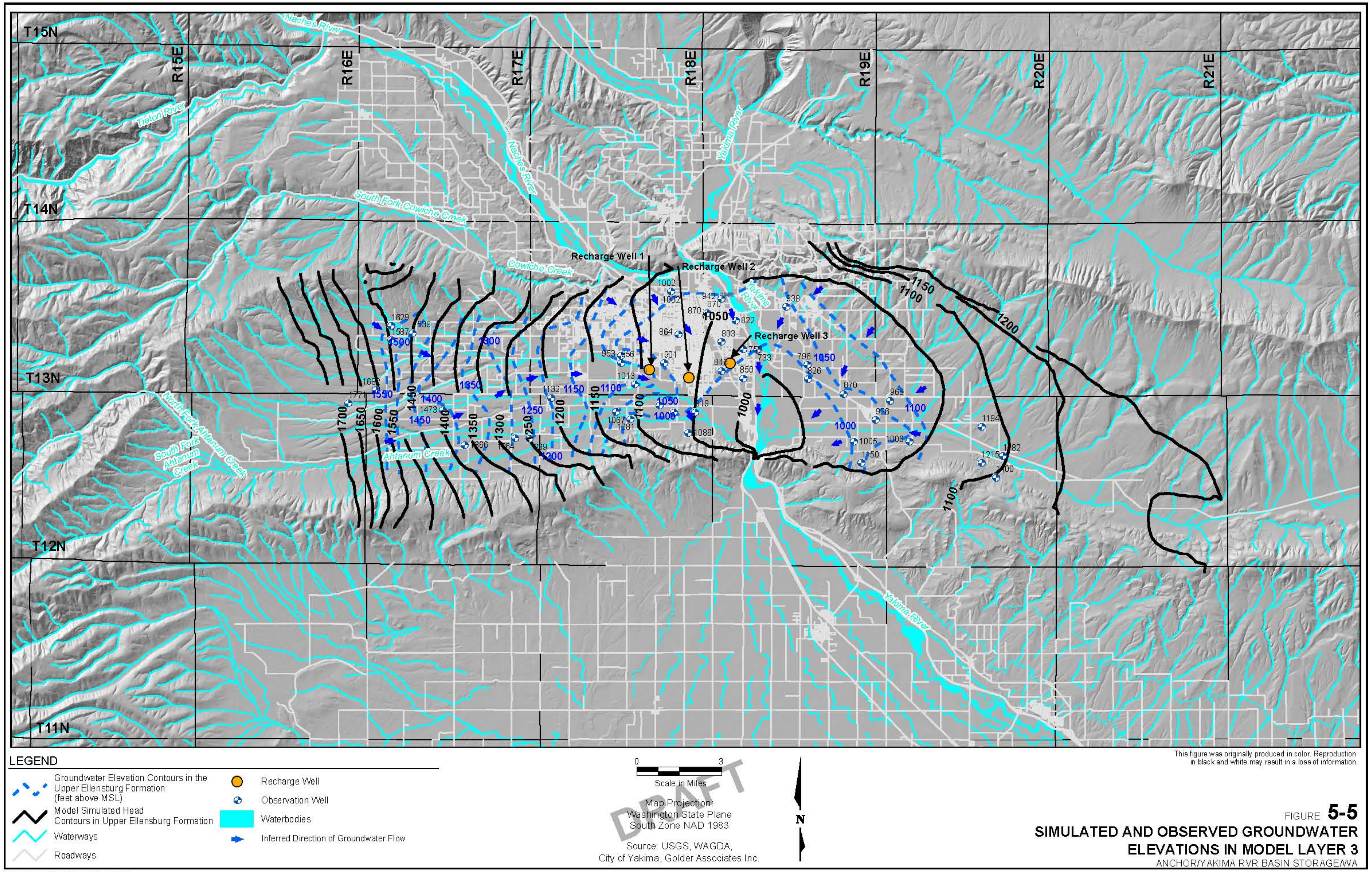



FIGURE **5-5**

**SIMULATED AND OBSERVED GROUNDWATER ELEVATIONS IN MODEL LAYER 3**

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**Golder Associates**

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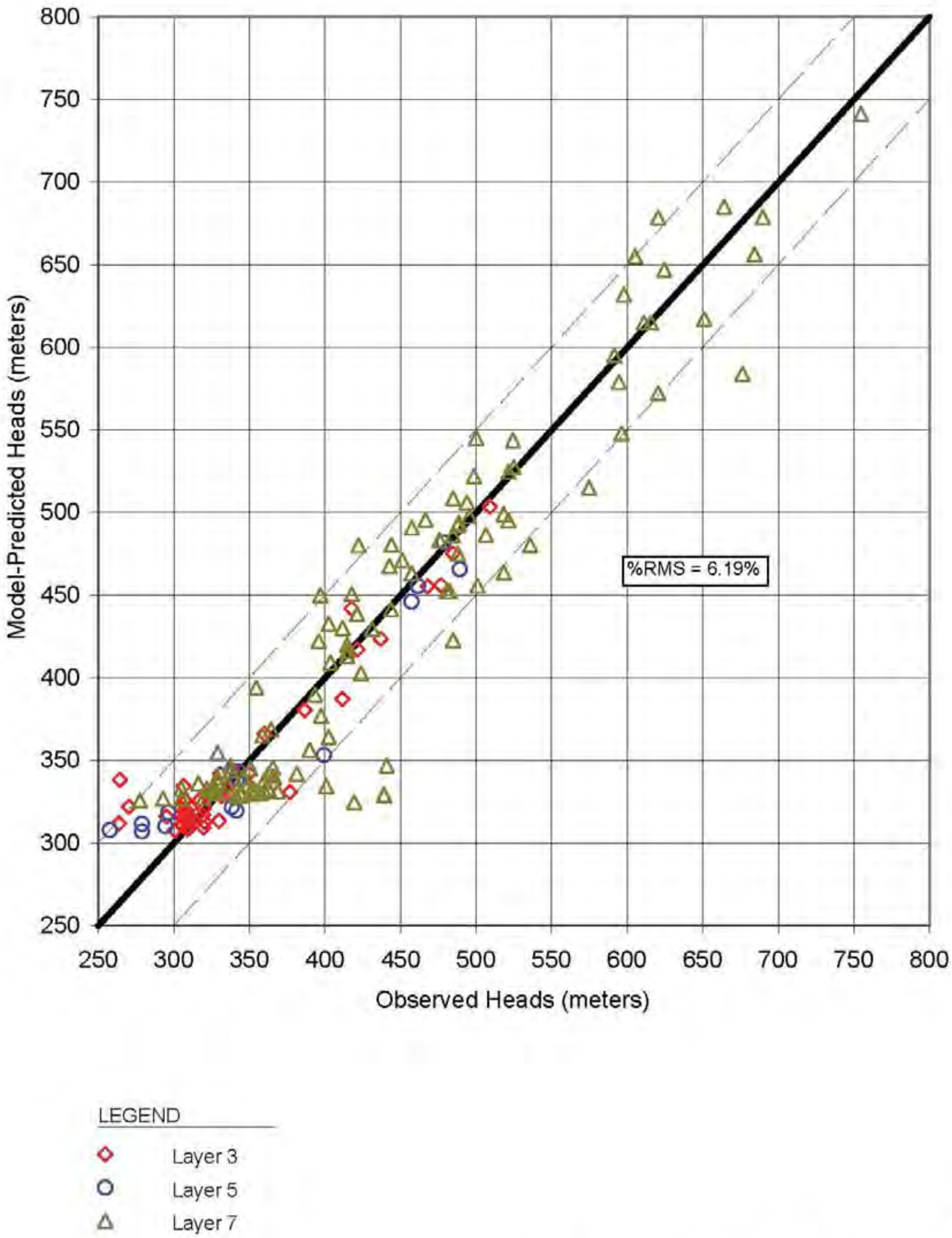


FIGURE **5-6**
**CORRELATION OF OBSERVED AND MODELED GROUNDWATER LEVELS**
ANCHOR/YAKIMA RVR BASIN STORAGE/WA

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**Golder Associates**

### 5.2.2 Direct Injection Model Simulation Results – Passive Recovery

The direct injection simulation included recharging water into the three wells for six months (i.e., October to March) at a constant rate of 2,000 gpm (4.46 cfs) each. Recharge ceased for the subsequent six months, and the cycle was repeated for nine years. Total recharge to the aquifer for the model simulation was approximately 4,800 acre feet. The average annual injection rate was 6.7 cfs (4.46 cfs x 3 wells x 0.5 year). The purpose of the direct injection simulation was to estimate the quantity of recharged water that discharged from the aquifer system to the Yakima River (thereby increasing flows) and to determine how much water remained in storage. The model used 20 stress periods, each of six months duration, and model results were generated at monthly time intervals.

Direct injection resulted in an immediate increase of aquifer storage and a delayed seepage of water to the Yakima River. After the first six-month injection cycle, the seepage rate to the Yakima River was 0.6 cfs, or approximately 200 acre feet from April through September. Direct injection during winter months for 10 years produced a seepage rate of approximately 4 cfs to the Yakima River at the end of the 10-year period with approximately 60 percent return flow efficiency, or approximately 1,400 acre feet from April through September (Table 5-3). Although the model was run for only 10 years, the trend of seepage to the river during the time of the simulation was asymptotically approaching the average annual direct injection rate of 6.7 cfs (Figure 5-7). This would deliver approximately 2,400 acre feet to the Yakima River from April through September. Therefore, if injection occurs over an extended period of time, the discharge to the Yakima River from injection is assumed to approach the average injection rate.

**TABLE 5-3**

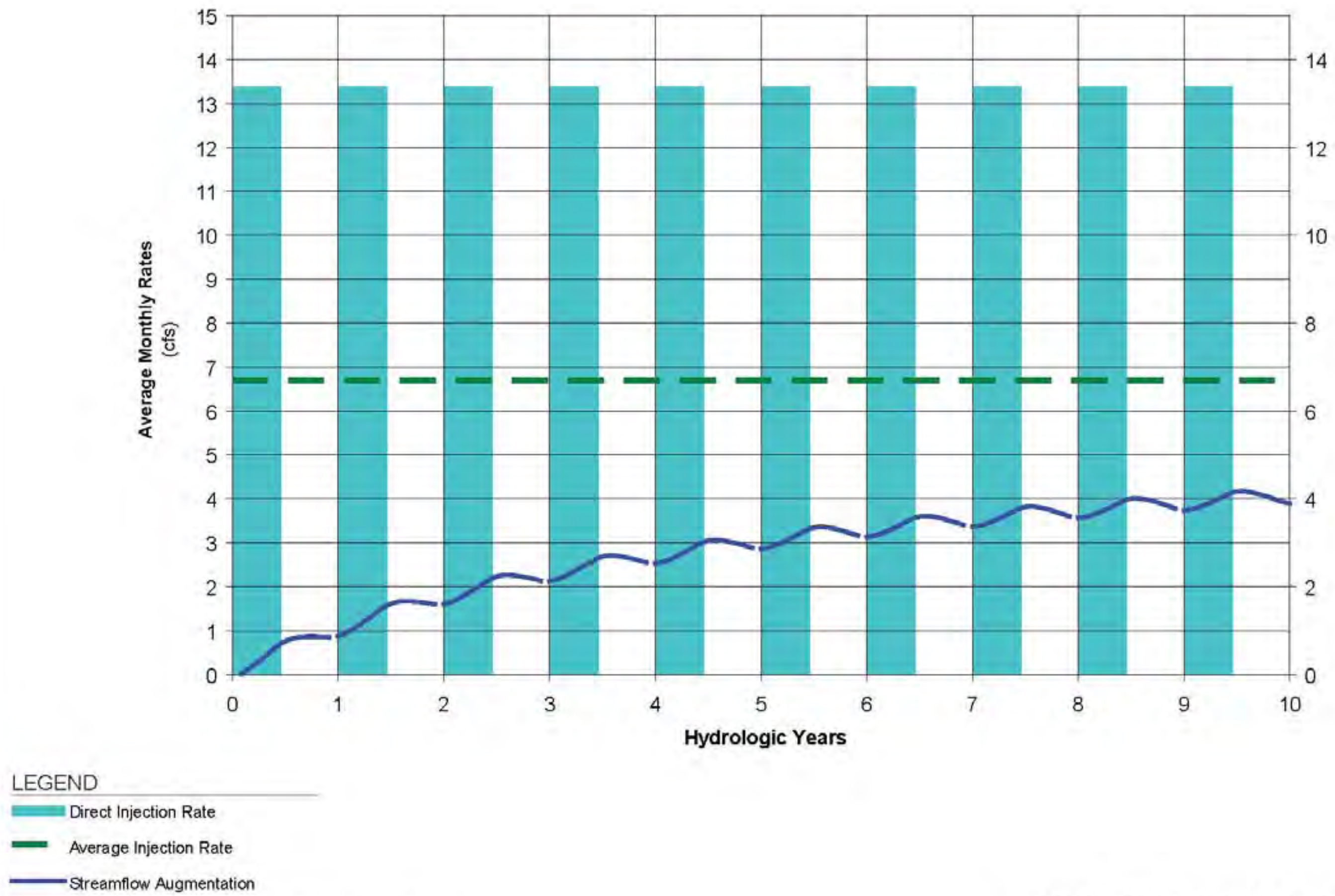
Recharge Volumes, Increased Aquifer Storage, Storage Efficiency (i.e., recoverable volumes) and Streamflow Augmentation

(based on injection of 6,000 gpm for six of the year)

| Year | Cumulative Recharged Water Volume (af) | Increased Aquifer Storage Volume Above Baseline (af) | Storage Efficiency[1] (%) | Streamflow Augmentation | |
|---|---|---|---|---|---|
| | | | | (cfs)[2] | (acre-feet)[3] |
| 1 | 5,175 | 4,800 | 92% | 0.9 | 298 |
| 2 | 9,975 | 8,550 | 86% | 1.6 | 585 |
| 3 | 14,700 | 11,850 | 81% | 2.1 | 792 |
| 4 | 19,500 | 14,850 | 76% | 2.5 | 946 |
| 5 | 24,225 | 17,625 | 73% | 2.9 | 1,070 |
| 6 | 29,025 | 20,100 | 69% | 3.1 | 1,173 |
| 7 | 33,825 | 22,425 | 66% | 3.4 | 1,260 |
| 8 | 38,550 | 24,600 | 64% | 3.6 | 1,335 |
| 9 | 43,350 | 26,700 | 62% | 3.7 | 1,400 |
| 10 | 48,150 | 28,575 | 59% | 3.9 | 1,442 |

Notes:

1. Recoverable Volume = [Increased Aquifer Storage] / [Recharged Volume] * 100
2. Rate at end of 6 months following a recharge period; cumulative volume of the period April through September.




*Note: Recharge is to the deep Ellensburg Formation.*
*See text for complete explanation.*

FIGURE **5-7**
**SIMULATED DIRECT INJECTION AND STREAMFLOW AUGMENTATION RATES**
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During the initial injection periods, aquifer storage continued to increase, though at a decreasing rate, as seepage to the Yakima River increased (Figure 5-8). This is described as a decrease in storage efficiency. When the storage efficiency drops to zero, seepage out of the aquifer will equal the average annual direct injection rate. An exponential trend line fit to a semilog plot of the storage efficiency output indicates that equilibrium between injection and seepage rates would be reached in several decades (Figure 5-9).

The significant lag time to achieve full steady state is due to the deep and the well-confined nature of the portion of the aquifer to which water is being directly injected. However, the significant lag time also causes the seepage rate to be relatively constant year-round and from year-to-year as it develops, and does not strongly reflect the seasonal (six-month) character of the recharge cycle.

Streamflow augmentation as a result of direct injection with passive recovery is assumed to be equal to the 60 percent average annual recharge rate after 10 years of seasonal injection. Using the modeling example, injection at an average rate of 6.7 cfs (13.4 cfs for six months) for 10 years produces 4 cfs of constant discharge to the Yakima River. Similarly injection at an average annual rate of 9 cfs (18 cfs for six months) would produce 5.2 cfs of constant discharge after 10 years of seasonal injection.

### 5.2.3 Extrapolation of Model Results to Active Recovery

Active recovery involves the recovery of increased aquifer storage resulting from direct injection. After the first annual cycle, 4,800 acre feet of the recharged water remained in the aquifer (i.e., 92 percent of the recharged water; Table 5-3, Figure 5-8). The increased aquifer storage is reflected by increased groundwater levels. Groundwater levels rise at the recharge points during the winter injection months and dissipate during the summer months when surface water is not used for direct injection. At an injection rate of 6.7 cfs (2,000 gpm at 3 wells), there is approximately 9 feet of residual water level rise at the injection points six months after injection stops, and before the next injection cycle starts (Figure 5-10). This is consistent with previous modeling results (Golder, 2002).

Active recovery will still result in seepage to the Yakima River, but will be less than would occur under passive recovery.

With continued injection without recovery, aquifer storage continued to increase, though at a decreasing rate, as seepage to the Yakima River increased. Direct injection during winter months for 10 years resulted in an increased aquifer storage of approximately 30,000 acre feet and a recovery efficiency of approximately 60 percent.

If injected water is recovered annually, recovery efficiency is high and most of the water can be recovered (e.g., 92 percent) with minor increases in Yakima River flows. If recovery is not conducted every year but is deferred, a smaller portion of the total injected water may be recovered without decreasing Yakima River flows, but the total recoverable amount of water will be larger than in a single year of annual recovery.

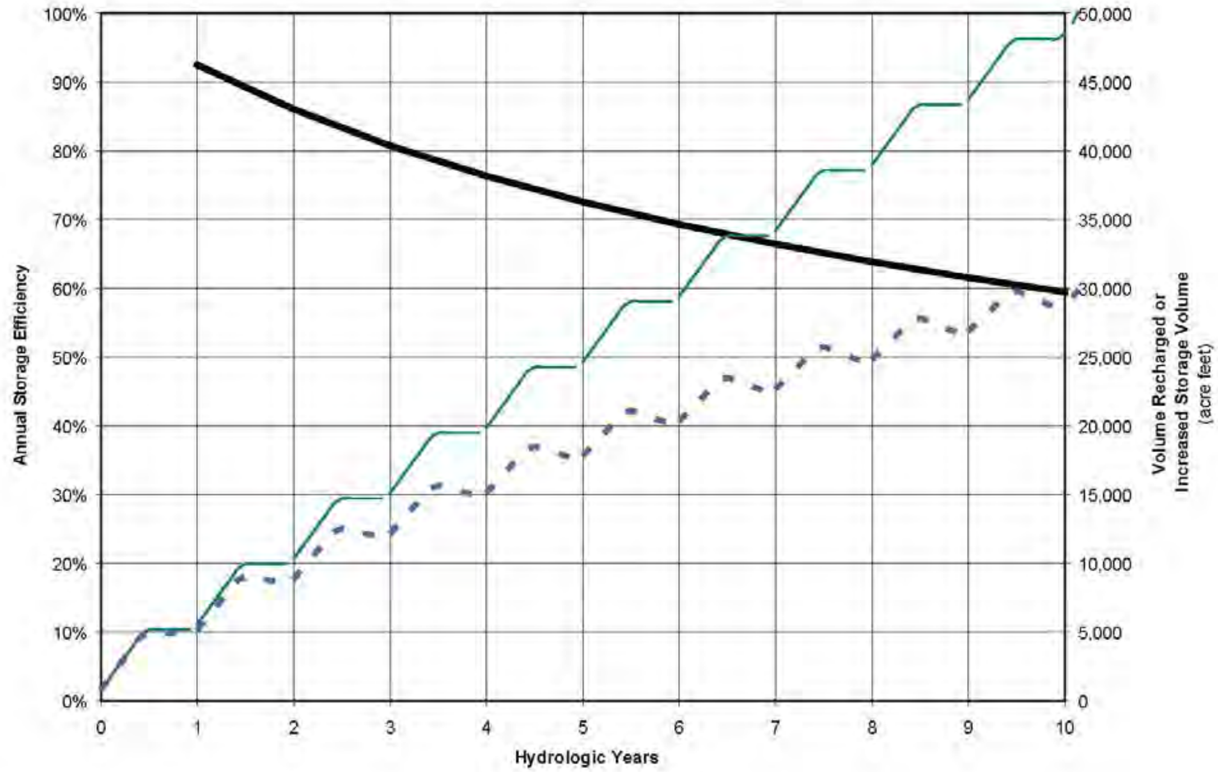
### 5.2.4 Well & Distribution System Limitations of Direct Injection

Individual well recharge rates are a function of aquifer properties and well efficiencies. A well should be able to receive (recharge) as much water as it can withdraw. Individual city of Yakima wells in the Ahtanum Valley yield between 2,000 gpm and 3,000 gpm. A pilot direct injection test has been operated at a rate of 1,200 gpm, and indicated that higher recharge rates were feasible. Well efficiencies typically decrease during injection cycles due to clogging by distribution system scale, sediment, or biofouling.

Where chlorinated water is used, biofouling is not considered a serious contributor to decreased well efficiency. Well efficiency decreased by approximately 25% during one month of recharge, but was fully restored during the recovery phase. Distribution system scale was identified as the principal contributor to decreased well efficiency in the Yakima pilot test (Golder, 2001).

Pressure builds up in an injection well as a result of increased water levels in the aquifer, and any decreases in well efficiency. Increased pressure may result in decreased injection rates if required injection pressures exceed distribution system pressures. Typical municipal distribution system pressures are on the order of 50-100 pounds per square inch (psi; ~115-230 feet of head of water). This can be increased in distribution systems dedicated to direct injection, or partially isolated from municipal distribution systems. Additionally, distribution system pressures locally decrease in the immediate vicinity of an injection well in response to the demand created by the injection well.

Theoretical simulated water levels in the injection wells show an increase of approximately 140-280 feet relative to static water levels (Figure 5-11). These water levels are a function of aquifer pressures only, and do not account for well efficiency losses (i.e., ideal well response – actual pressures at the wellheads during injection will likely be higher). Such head buildups are feasible if current static aquifer water levels are significantly below ground surface (e.g., in the Blackrock-Moxee area). Alternatively, these head buildups may present practical constraints on recharge rates if aquifer water levels are near ground surface or are flowing artesian under static conditions (e.g., possibly in the Kittitas and Ahtanum Valleys).




LEGEND

- Annual Storage Efficiency
- Monthly Volume Recharged
- Monthly Residual Storage Above Baseline

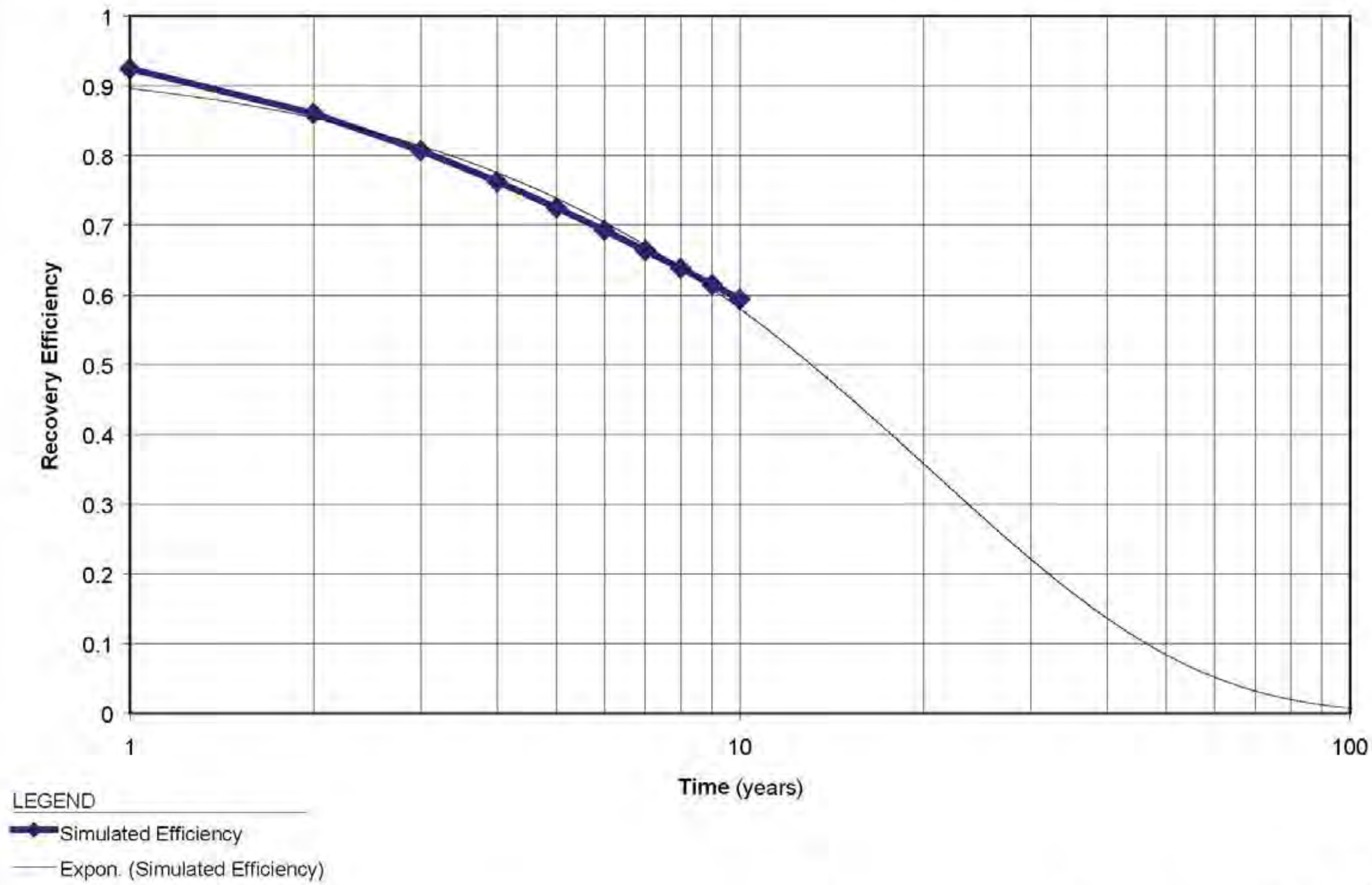
Note: This chart considers stored volume without recovery. Annual recovery would maintain recurring first year efficiency (e.g., 92%), bienniel recovery would maintain approximately the second year efficiency (e.g., 86%), etc. Recharge is to the deep Ellensburg Formation. See text for more complete explanation.

FIGURE **5-8**

**SIMULATED DIRECT INJECTION STORAGE EFFICIENCY WITH ACTIVE RECOVERY**

ANCHOR/YAKIMA RVR BASIN STORAGE/WA

**Golder Associates**




*Note: Recharge is to the deep Ellensburg Formation.*
*See text for complete explanation.*

FIGURE **5-9**
**DIRECT INJECTION ACTIVE RECOVERY EFFICIENCY (ASR) EXTRAPOLATED INTO THE FUTURE**
ANCHOR/YAKIMA RVR BASIN STORAGE/WA

**Golder Associates**

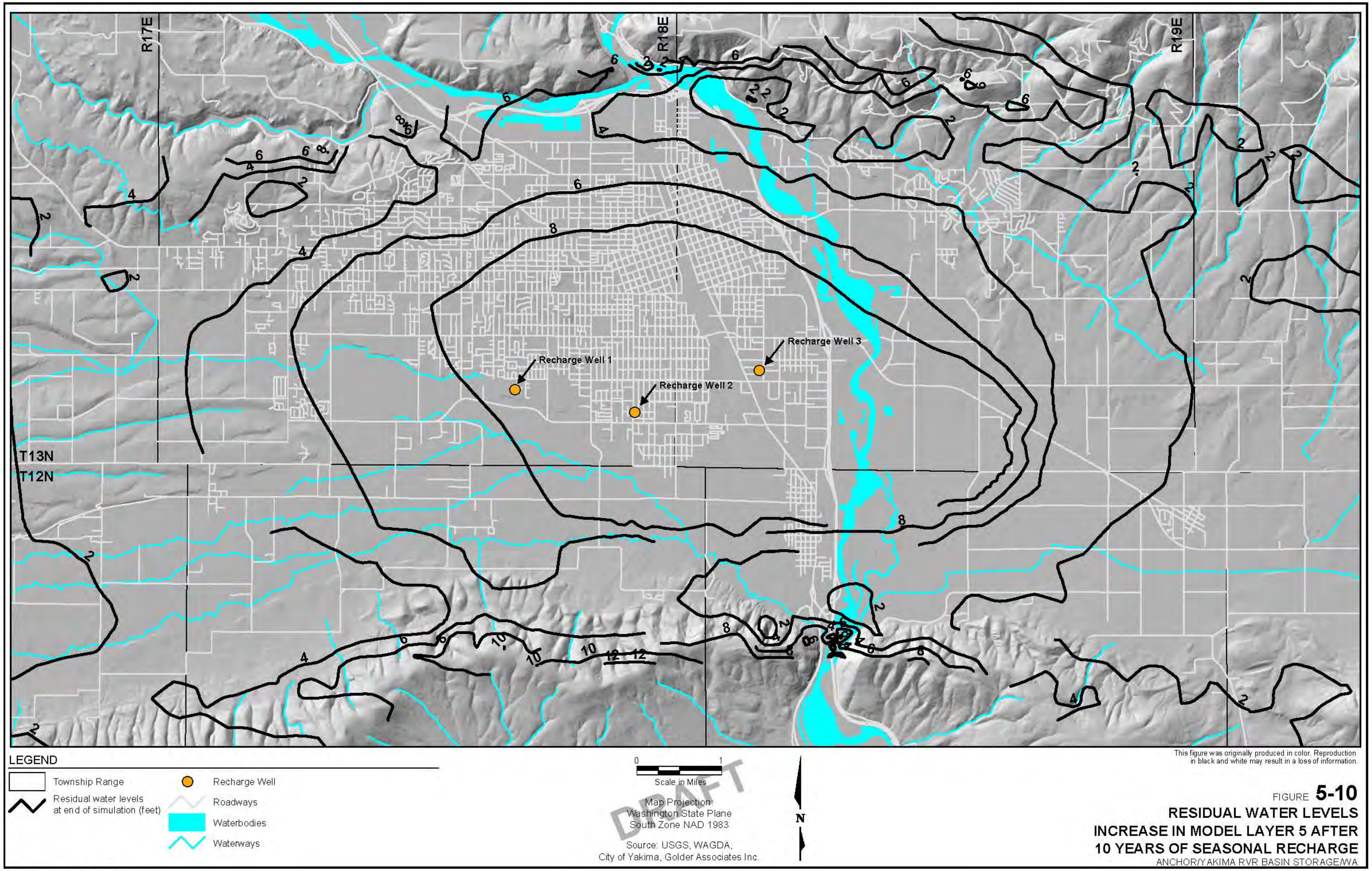



FIGURE 5-10
RESIDUAL WATER LEVELS INCREASE IN MODEL LAYER 5 AFTER 10 YEARS OF SEASONAL RECHARGE

ANCHOR/YAKIMA RVR BASIN STORAGE/WA

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Golder Associates

### 5.2.5 Model Limitations

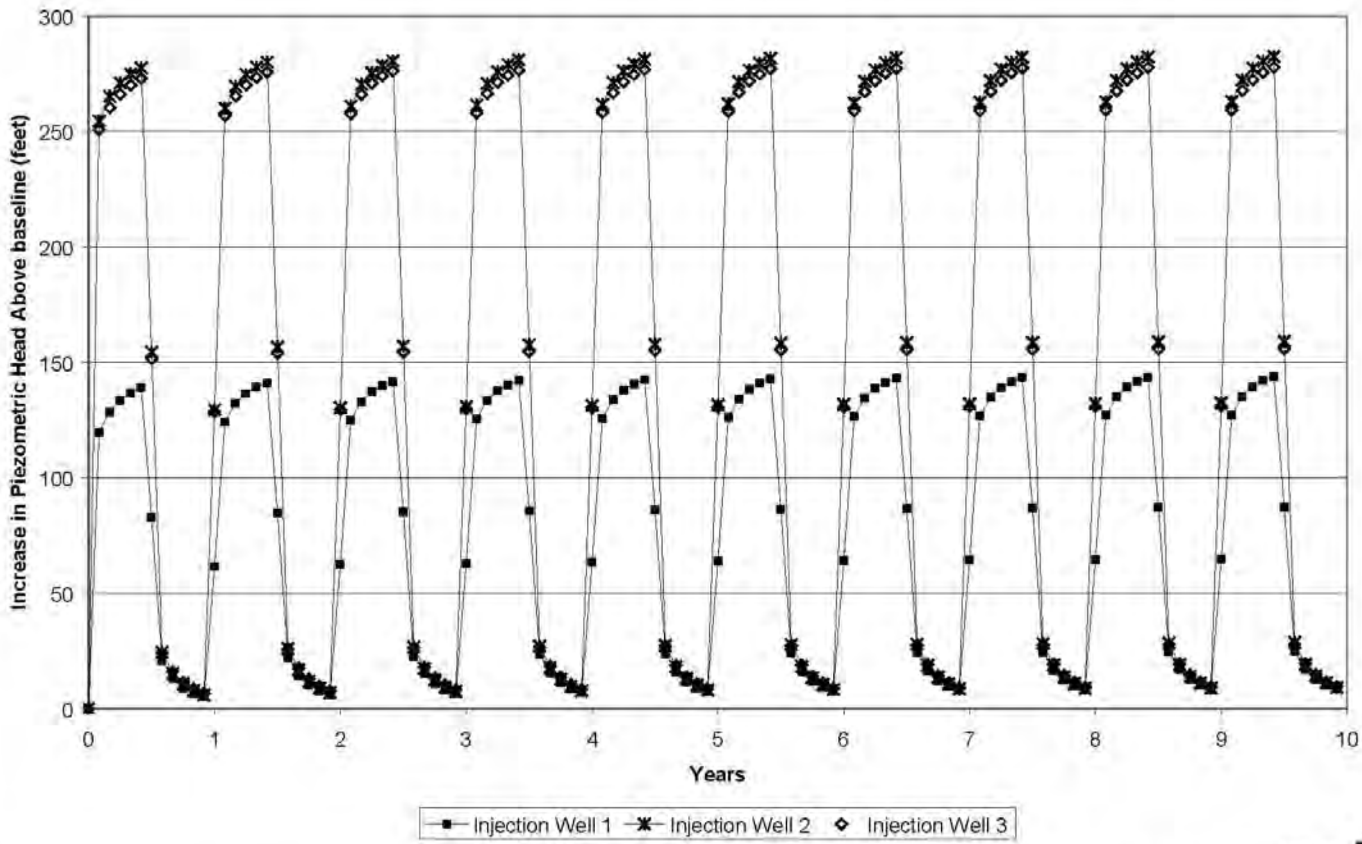
Simulation of the groundwater flow system was calibrated to presumed original static water conditions, and was not calibrated to transient conditions (e.g., seasonally variable recharge or groundwater withdrawals).

The influence of seasonal recharge on the deep aquifer to which water was directly injected is expected to be significantly less than the influences of direct injection, and less than the numerical accuracy of the model.

Groundwater levels vary significantly in response to drought conditions. This response to drought conditions is speculated to be primarily caused by aggressive pumping of the aquifer, as opposed to changes in climatic conditions. The evaluation of the effects of direct injection is conducted without consideration of pumping from other sources because the purpose of the assessment is to evaluate the impacts of direct injection as an independent action. It is acknowledged that pumping from the same aquifer by other activities may alter the actual impacts from direct injection recharge of groundwater. However, under the influence of other pumping, the quantified benefits of direct injection will offset potential impacts from such pumping and result in the same net benefit to available water.

The computer simulation of direct injection considered only the year-over-year injection to groundwater during the winter (i.e., annual injection and recovery cycles). This includes increase in aquifer storage (i.e., recoverable water in a groundwater balance neutral context) and resulting augmentation of streamflow. Withdrawal of that water under active recovery scenarios was not simulated with the model. However, analysis of the data provides a reasonable qualification of the interpretation.

The numerical computer simulation considered recharge at three wells, each at a rate of 2,000 gpm (total of 6,000 gpm) for six months (e.g., October through March) for an annual recharged volume of 4,800 acre feet. Application of the numerical computer simulation to specific sites extrapolates the simulation results to four wells, each at a rate of 2,000 gpm. The hydraulic responses are assumed to be linear, and are increased by a factor of 4:3 (1.33). Therefore, the total rate at each site is 8,000 gpm over six months to result in a recharge volume of 6,400 acre feet at each site.




*Note: Simulated injection rate of 2,000 gpm at each well*

FIGURE **5-11**

**HEAD BUILDUP AT INJECTION WELLS**

ANCHOR/YAKIMA RVR BASIN STORAGE/WA

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**Golder Associates**

## 5.3 CITY OF YAKIMA ASR (AHTANUM VALLEY)

ASR concepts for the city of Yakima are well-developed. A site has been established in the Ahtanum Sub-basin. Previous work that has been completed includes a technical compilation for the application of ASR (Golder, 2000a), an ASR pilot test plan (Golder, 2000b), an ASR pilot test (Golder, 2001) and a computer modeling simulation of the application of ASR (Golder, 2002).

### 5.3.1 Recharge Water Source & Delivery

The proposed source of recharge water for ASR for the city of Yakima ASR program is the Naches River. A surface water treatment plant with a nominal capacity of 25 million gallons per day (mgd) owned by the city of Yakima exists at approximately river mile 10 (Figure 5-12). The plant operates at less than 50 percent capacity during the winter months. A 48-inch transmission line delivers water to the service area of the city of Yakima, and is connected by a distribution system to three large municipal drinking water wells (i.e., ranging in depth of approximately 800 to 1,200 feet, and individual capacities of 2,300 to 3,000 gpm). Additional wells are planned for installation. Use of the existing surface water treatment plant and distribution system for an ASR program can be arranged through an agreement with the city of Yakima. Existing infrastructure capacity can provide the availability of up to approximately 12 mgd during the winter (approximately 8,000 gpm or 18 cfs). It is assumed that this amount of water from the Naches River is available for ASR injection.

The delivery of water from the drinking water treatment plant to wells could be limited by two factors: transmission capacity and minimum system pressure requirements for fire protection (i.e., 30 psi). These constraints could be addressed by increasing the size of transmission components and/or configuring the direct injection recharge system to be interruptible. The recharge system could be controlled by distribution system pressure gages that would shut off direct injection if the system pressure drops below a predetermined threshold (e.g., 45 psi).

### 5.3.2 Water Quality Considerations

Water quality was analyzed during a pilot ASR test (Golder, 2001). The pilot test included storage of recharged Naches River surface water in the Upper Ellensburg Formation aquifer for 55 days. The primary reactions between the recharged water and both aquifer water and aquifer materials were documented to be linear mixing between recharged water and aquifer water, as indicated by environmental tracers, and no significant chemical reactions were identified. A high degree of compatibility among the various components was observed. No parameters of concern for drinking water quality were identified, and water quality remained potable throughout the pilot test, including during the recovery stage.

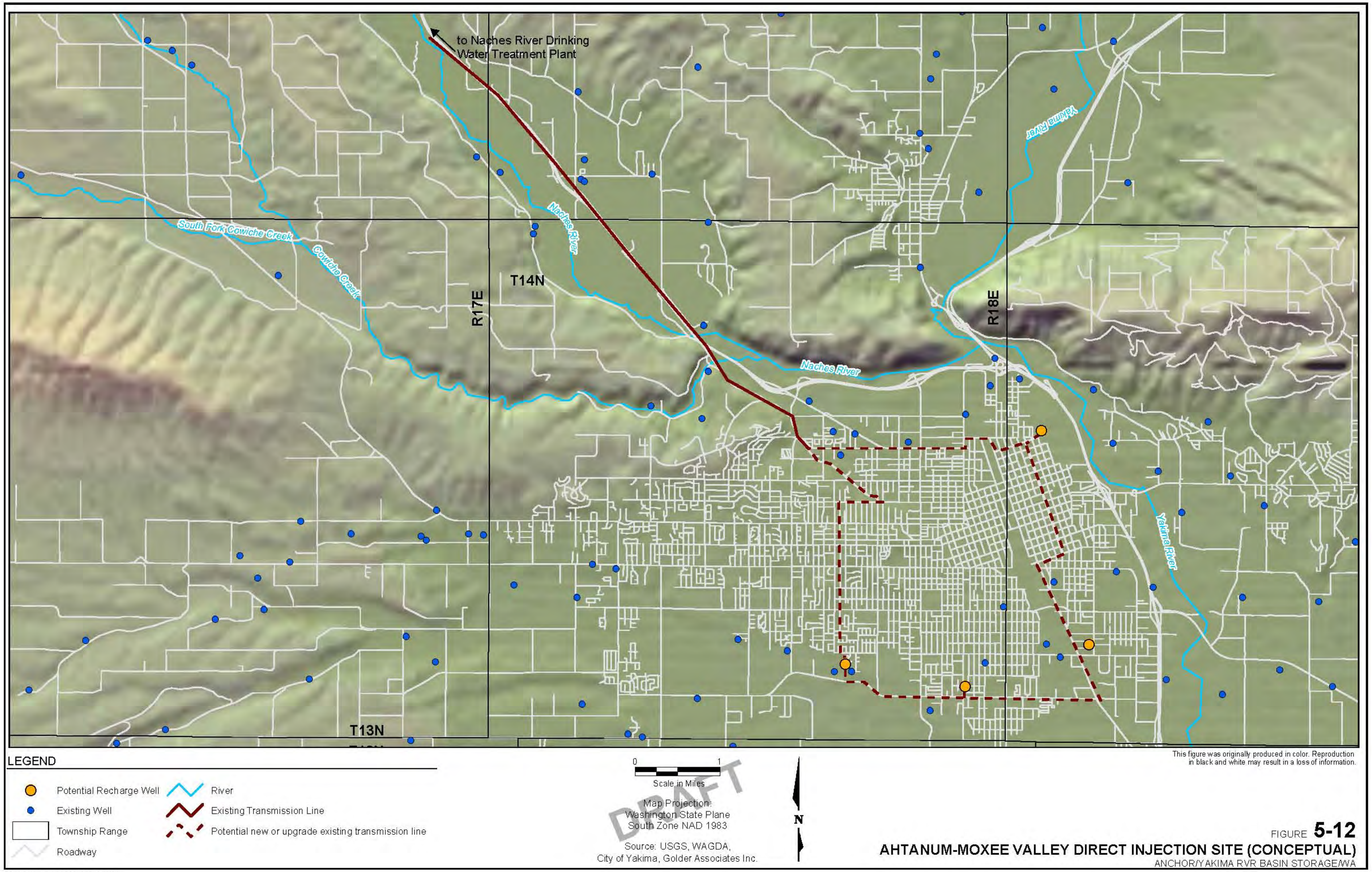


FIGURE **5-12**

**AHTANUM-MOXEE VALLEY DIRECT INJECTION SITE (CONCEPTUAL)**

ANCHOR/YAKIMA RVR BASIN STORAGE/WA

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**Golder Associates**

### 5.3.3 Evaluation of Benefits

The effects of direct injection on TWSA, for both passive and active recovery, are based on extrapolations of the computer simulation (see Section 5.2). For both passive and active recovery, an injection rate of 8,000 gallons per minute or 17.9 cfs (which is the capacity of the transmission line from the Naches Water treatment plant) is assumed, and approximately 6,400 acre feet would be injected for six months, for an average annual recharge rate of 9 cfs.

For passive recovery, seepage would increase with continued seasonal injection recharge, and a long-term year-round equilibrium seepage rate of 9 cfs to the Yakima River will result. This provides approximately 3,200 acre feet of TWSA to the Yakima River above the Parker gauge during the 6-month period of April to September when equilibrium between recharge and seepage is reached.

With active recovery, seepage to the Yakima River will be less than under passive recovery but still provides a net increase of seepage to the river. The transient effects of seasonal pumping to recover the injected water and the cumulative effects on seepage to the Yakima River from year-after-year injection are complex. During the first injection cycle, recharge of ~6,400 acre feet (i.e., 18 cfs at the expected available treatment plant capacity) has a high recovery efficiency (92 percent) and results in a recoverable volume of ~5,900 AF, with the remaining volume discharging to the Yakima River over time at a rate of about 1.2 cfs. This will deliver approximately 200 AF to the Yakima River over a six-month period.

After 10 years of injection (without recovery), the cumulative recovery efficiency will be lower than if it is recovered on an annual basis (60 percent of the cumulative volume recharged over 10 years, as opposed to 92% if it is recovered on an annual basis; Table 5-3). This is because more water will have seeped out of aquifer storage to the river, achieving a seepage rate of about 5.2 cfs (~1,900 AF over a sixth month period). A possible active recovery scenario would be to build up aquifer storage over a period of 5 to 10 years, and achieve a seepage discharge rate of 3 to 5 cfs. After 10 years of buildup, active recovery of the "in-year" injection volume could occur at higher rate without immediate reduction in the seepage discharge rate of 3 to 5 cfs.

The benefits of direct injection may be realized in several ways. Four end member scenarios are described, followed by one hybrid scenario:

1. Replacement of Current Surface Water Diversions: Replacing current municipal summer surface water diversions with ASR would result in a direct increase to streamflow during the 6-months from April to September. Recovery of 6,000 AF of ASR would improve TWSA initially by 6,000 AF. Yakima river flows would be additionally by augmented by between 0-1.2 cfs of seepage of injected water from the aquifer.

2. Pump and Dump: Direct discharge of ASR water to the Yakima River (i.e. "pump & dump") would increase Yakima River flows by 6,000 AF in the 6 months from April to September. This would also provide additional water quality benefits of clean clear cold water to the Yakima River, which is water quality impaired with respect to turbidity, temperature, and other parameters.

3. Satisfying Future Demand: Satisfying future demands with ASR would reduce demand pressure on the Yakima River by 6,000 AF. It would also increase Yakima River streamflows over current levels by the nonconsumptive portion withdrawal (i.e. return flows from wastewater treatment would essentially put a portion of the ASR storage directly back to the river). This would be on the order of 2,700 AF if used for city of Yakima municipal water supply (e.g., 45 percent nonconsumptive use from April through September; Figure 5-13).

4. Passive Recovery: Allowing injected water to seep back to the Yakima River will increase TWSA by a maximum of 50% of the annual injection rate. This would augment Yakima River flows by approximately 3,200 AF, assuming an annual inject rate of 6,400 AF. Only 50% of the injected volume contributes to TWSA because seepage is constant year-round, including 50% of the seepage volume during the irrigation season (April through September) and 50% of the seepage volume during the irrigation off-season (October through March).

5. Intermittent Active Recovery: One approach to using groundwater storage is to only access or use stored groundwater during water short years. Water stored during non water short years may be saved or banked for later use. Intermittent use would maximize the quantity of stored water for water short years because the recoverable amount of water is more than just what was stored in the most recent recharge season, and seepage rates to the Yakima River will be higher than if the injected water were recovered annually. For instance, direct injection during winter months for 10 years at a rate of 8,000 gpm (four wells at 2,000 gpm each) results in an increased aquifer storage of approximately 38,000 acre feet and an estimated seepage rate of 5.2 cfs to the Yakima River (see figure 5-8, which presents a recharge scenario at rate of 6,000 gpm through three wells). Recovery of the additional stored water may require additional recovery wells.

Active recovery can be more efficient than passive recovery in making water available during the irrigation season because most of the stored water can be immediately pumped out and made available during the irrigation season. Passive recovery may be on the order of 50% less efficient because it delivers water to the stream year-round – not only in the irrigation season. The availability of water during water-short years can be maximized by actively recovering injected water only during water-short years. Not recovering water in non-water-short years will increase the seepage rate to the Yakima River and increase the cumulative aquifer storage and associated recoverable water. Additional wells beyond the direct injection wells may be needed to recover the desired volume of water at an appropriate rate.

## 5.4 CITY OF ELLENSBURG (KITTITAS VALLEY)

From a hydrogeological standpoint, the Kittitas Valley is a close analogy of the Ahtanum-Moxee Valley. Both are doubly-plunging synclinal structures (i.e., basins) filled with Ellensburg Formation and underlain by basalts of the Columbia River Group. Both valleys are covered by a shallow veneer of unconsolidated sands and gravels through which the Yakima River flows.

Therefore, the modeling and injection recovery analyses for the City of Yakima ASR system (Ahtanum Valley) are applied to the City of Ellensburg to the Kittitas Valley.

### 5.4.1 Recharge Water Source and Delivery

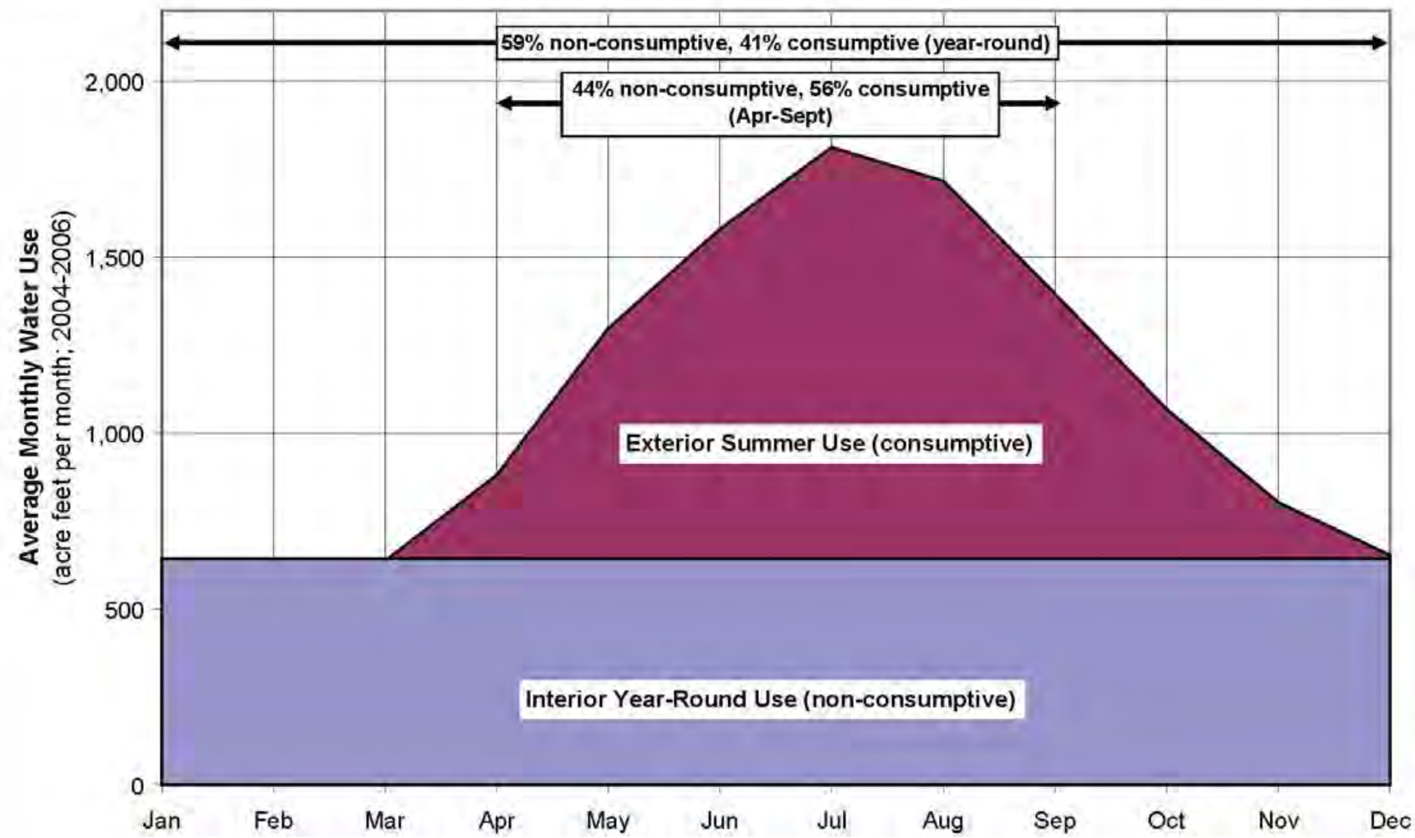
The principal difference between the Yakima and Ellensburg concepts is how recharge water is obtained. An existing drinking water surface treatment plant on the Naches River is available for injection in the Ahtanum Valley, but no such plant exists as a source of recharge water in the Kittitas Valley. However, the city of Ellensburg has a shallow Ranney well, that withdraws water from the alluvial aquifer that is in close hydraulic continuity with the Yakima River (Figure 5-14). The well (called the "City Wells") is located approximately 7 miles upstream of the City. Withdrawing water from this Ranney well is equivalent to the direct diversion of water from the Yakima River. Treatment of the water as if it is surface water is required because of the close hydraulic continuity between the Yakima River and the Ranney well.

The capacity of the City Wells, as indicated by associated water rights, is approximately 7 mgd (10.8 cfs). Capacity may be naturally higher in the winter, and may be enhanced by surface flooding of the site. The City has boosted production in the past by flooding of the site (personal communication, Mr. John Akers, Public Works Director, city of Ellensburg).

The transmission/distribution system from the City Wells is very similar to the City of Yakima. A major transmission line with a nominal capacity of approximately 16 cfs extends from the City Wells site to the city of Ellensburg city limits. The city is currently planning to replace the supply from the City Wells with deep groundwater wells. Use of the City Wells and the associated transmission system is a viable option for a direct injection ASR project.

The Washington Department of Health has determined that water withdrawn from the City Wells needs to be treated according to the Surface Water Treatment Rule. Therefore, a surface water treatment plant will be needed if the City Wells and the associated transmission system are used for an ASR program. .

Recharge through a series of direct injection wells along the axis of the valley is proposed (Figure 5-14). Well withdrawal capacities, used here as an indication of recharge capacities, have typically been less than 2,000 gpm, but new well designs, which have not yet been installed, may yield up to 2,000 gpm. The target injection rate is 2,000 gpm through each of four wells for a total injection rate of 8,000 gpm (18 cfs). One of the injection wells could be located at the treatment plant site so that the existing transmission system with a capacity of 16 cfs will be sufficient to deliver the remaining 13.5 cfs to other injection sites.




Data provided by the city of Yakima.

FIGURE 5-13
CITY OF YAKIMA MONTHLY WATER USE
ANCHOR/YAKIMA RVR BASIN STORAGE/WA

Golder Associates

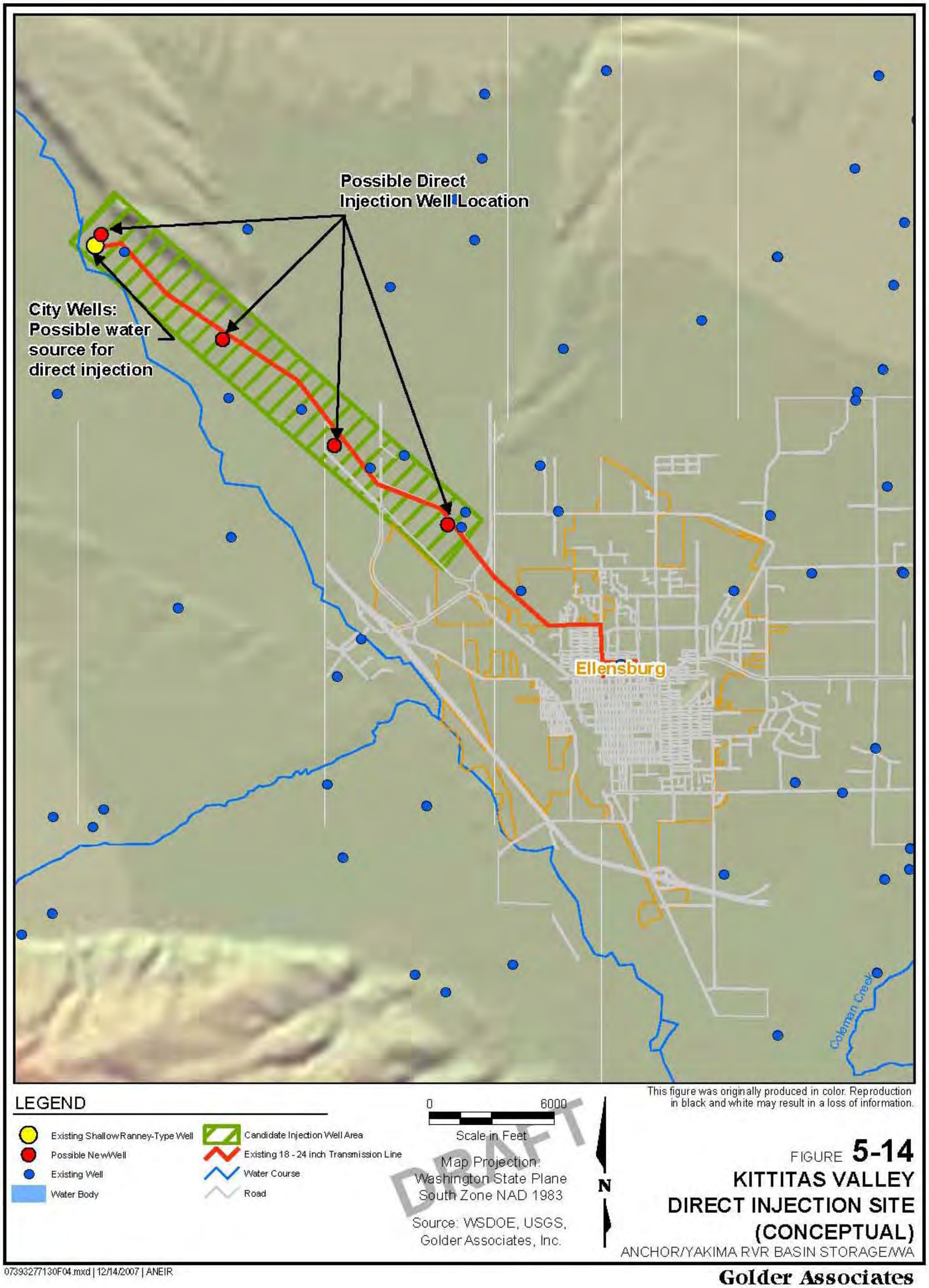



FIGURE 5-14
KITTITAS VALLEY
DIRECT INJECTION SITE
(CONCEPTUAL)

### 5.4.2 Water Quality Considerations

A surface water treatment plant will be necessary to produce potable quality water for injection. A high degree of water quality compatibility between surface water from the Naches River and groundwater from the Ellensburg Formation was shown in the city of Yakima ASR pilot test and therefore, there are minimal water quality concerns.

The Kittitas Valley and Ahtanum Valley direct injection settings are very similar. Both use the same water source (i.e., the Yakima River or groundwater in very close hydraulic continuity with the Yakima River) and both use the same formation to store water (the Upper Ellensburg Formation). Therefore, the water quality considerations of direct injection in the Kittitas Valley is expected to be very similar to that of the Ahtanum Valley, in which no water quality concerns were identified (Golder, 2001)

### 5.4.3 Evaluation of Benefits

The benefits for the Kittitas direct injection are similar to those for the Ahtanum Valley, with the following differences:

The city of Ellensburg relies 100 percent on groundwater. Therefore, active recovery would not replace any existing municipal surface water diversion. However, active recovery of injected water could be delivered to the Town or Cascade Irrigation Canals, which pass approximately 600 feet away from the City Wells site, and replace Yakima River surface water diversions immediately upstream of the City Wells site that now supply irrigation water to those canals.

Provide water for future increased out-of-stream demands. This would reduce demand pressure on the Yakima River by 6,000 AF. It would also increase Yakima River streamflows by the nonconsumptive portion of the application to which it is applied in the 6 months from April to September. This would be on the order of 2,400 AF if used for city of Ellensburg municipal water supply (e.g., 40 percent nonconsumptive use from April through September; Figure 5-15).

Direct discharge of ASR water to the Yakima River (i.e. "pump & dump") would increase Yakima River flows by 6,000 AF in the 6 months from April to September. Some "fine tuning" of the ratio of direct discharge and use in the municipal system could provide additional short-term (i.e. days or weeks) increases to streamflow by both replacing surface diversions and directly augmenting streamflows from the ASR system. This would also provide additional water quality benefits of clean clear cold water to the Yakima River, which is water quality impaired with respect to turbidity, temperature and other parameters.

## 5.5 BLACKROCK-MOXEE VALLEY DIRECT INJECTION

Groundwater levels in the basalt aquifer system near Blackrock-Moxee have dropped significantly during the past 100 years. This has raised concerns with respect to the sustainability of this groundwater resource and the water supply that it provides (e.g., Moxee City, agricultural, domestic and other uses) as well as possible impacts on streamflows. It is assumed that there is hydraulic continuity between the basalt system and the Yakima River.

Although there is likely a significant lag time between the timing of pumping and the timing of potential impacts on streamflows (e.g., many decades), it is assumed that impacts will eventually approximately equal the rate of pumping.

Quantitative analysis of direct injection was not conducted for the Blackrock-Moxee area. However, the following combination of factors indicates that recovery efficiency of a direct injection and recovery program would be high:

- The area has very low recharge rates.
- The basalt aquifer system had flowing artesian pressure before it was developed (see the cover of the USGS Yakima River series of reports; Vaccaro and Olsen, 2007, Jones and others, 2006).
- Water levels have decreased significantly from pumping of the aquifer.

The degree of hydraulic continuity between the basalt and the Yakima River is expected to be less than between the Upper Ellensburg Formation as modeled in this report. Therefore, the lag time between the time of injection and seepage back to the Yakima River is expected to be longer than simulated for the Upper Ellensburg Formation.

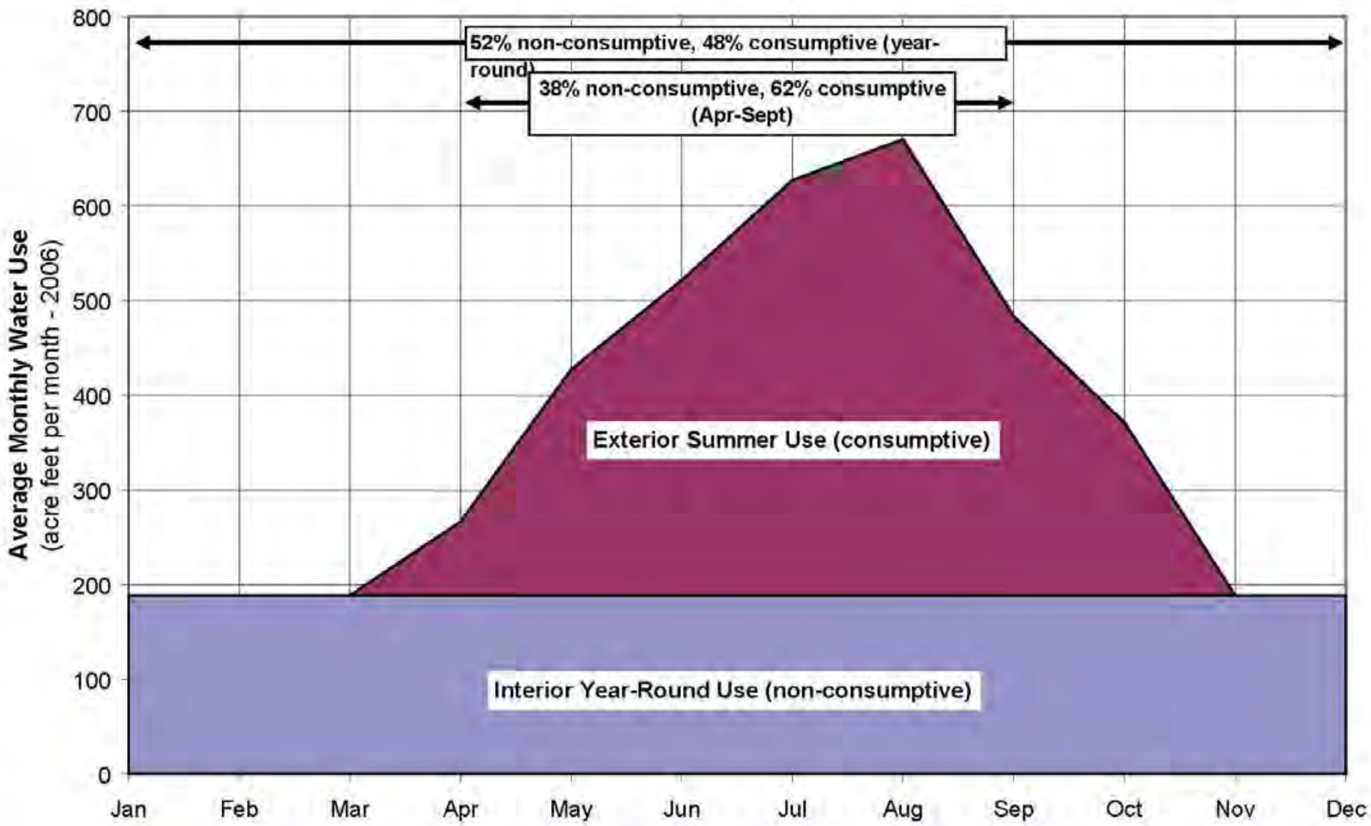
### 5.5.1 Blackrock-Moxee Direct Injection Recharge Water Source & Delivery

Yakima River water is identified as a source of water for direct injection. Shallow alluvial wells next to the river are proposed for acquiring water for direct injection (Figure 5-16). This will avoid the construction of a direct surface water diversion to obtain water of quality acceptable for direct injection. This method is called river bank filtration because it uses the natural filtration capacity of river bank sediments to obtain sufficiently clean water.

The source water wells are located near the greatest thickness of shallow alluvial sediments along the Yakima River in order to maximize the available drawdown and yield of wells (Figure 2-7 in Golder, 2002). The injection wells are sited in the general area east of the town of Moxee. The injection sites may be relocated depending on more detailed mapping of diminished water levels and/or of the distribution of actual pumping. The general alignment of the transmission line between the source water wells and injection sites follows public rights-of-way along State Route 24 for both ease of easement acquisition and access purposes.

Active recovery could deliver water directly the Roza irrigation canal that passes by the injection site and allow the reduction of surface diversions by the amount of inject water that is recovered (e.g., 6,000 AF). Hydraulic analysis of the irrigation canal operations with would have to be conducted to ensure that operations are not disrupted.

Alternatively, active recovery could be used to augment Yakima River flows by delivering water directly back to the Yakima River. Water recovered from the injection wells could be delivered back to the Yakima River using the same transmission line constructed to delivery water from the source wells next to the river to the injection site.




Data provided by the city of Ellensburg.

FIGURE **5-15**
**CITY OF ELLENSBURG MONTHLY WATER USE**
ANCHOR/YAKIMA RVR BASIN STORAGE/WA

**Golder Associates**

Passive recovery would best extend the sustainability of the groundwater resource, and offset impacts to streamflows. The time lag between injection and seepage back to the river has not been analyzed; however it is expected to be significant (e.g., many decades). The groundwater flow model currently under development by the United States Geological Survey may have the ability to provide an estimate of the time lag.

It is expected that most of the pumping in the Blackrock-Moxee area is for seasonal irrigation. Therefore, there may be existing wells that are available and may be retrofitted for direct injection during the off-irrigation season. This could reduce the cost of construction.

### 5.5.2 Blackrock-Moxee Direct Injection Evaluation of Benefits

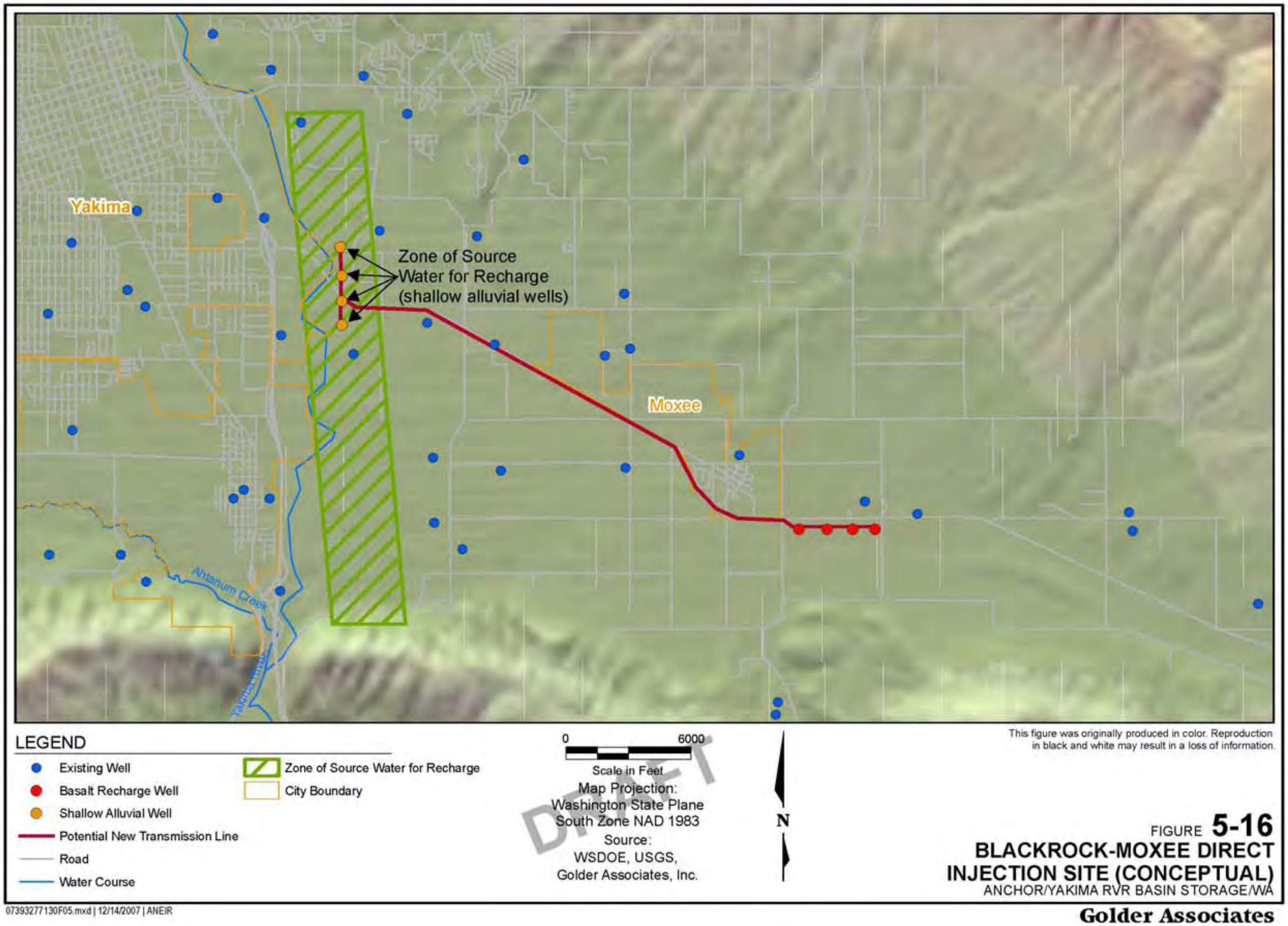
The benefits for the Blackrock-Moxee direct injection and passive recovery include off-setting potential impacts to streamflows and extending the sustainability of the groundwater resource. As described in Section 5.3.3 (Evaluation of Seepage to Streamflow), impacts to streamflow (whether due to pumping or positive due to direct injection) are expected to be equal to the average annual rate of injection or withdrawal. Therefore, injection of 6,400 AF (i.e., 8,000 gpm through four wells for 6 months) will result in the augmentation of Yakima River flows by 9 cfs year-round once equilibrium in the seepage rate to the Yakima River is established (e.g., many decades), or 3,200 AF for 6 months (e.g., April through September). However, the significant lag time that is expected between the time of injection and realization of quantitative seepage to the Yakima River may not be considered feasible (e.g., greater than 100 years).

Active recovery of injected water could increase TWSA by 6,000 AF from April through September under two scenarios:

- Deliver recovered water to the Rosa irrigation canal to replace the diversion of an equivalent amount from the Yakima River for irrigation purposes.
- Deliver water directly back to the Yakima River.

Active recovery only in water short years would:

- Allow the replenishment of depleted groundwater storage.
- Provide a greater cumulative volume of stored water for withdrawal in one year than would otherwise be available by annual recovery (e.g., 18,000 AF if the injected water was recovered after five years of annual recharge, versus 6,000 AF that would only be available under an annual active recovery program).
- Augment streamflows through seepage.



Yakima
Zone of Source
Water for Recharge
(shallow alluvial wells)
Moxee
Ahtanum Creek
LEGEND
Existing Well
Basalt Recharge Well
Shallow Alluvial Well
Potential New Transmission Line
Road
Water Course
Zone of Source Water for Recharge
City Boundary
0
6000
Scale in Feet
Map Projection:
Washington State Plane
South Zone NAD 1983
Source:
WSDOE, USGS,
Golder Associates, Inc.
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This figure was originally produced in color. Reproduction in black and white may result in a loss of information.
FIGURE 5-16
BLACKROCK-MOXEE DIRECT
INJECTION SITE (CONCEPTUAL)
ANCHOR/YAKIMA RVR BASIN STORAGE/WA
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Golder Associates

## 5.6 WATER QUALITY

Understanding water quality dynamics is essential to evaluating the technical feasibility of an ASR program as well as showing compliance with regulatory programs. In addition, assessment of changes in water quality during ASR is useful for developing a greater understanding of the processes that affect ASR and its effectiveness.

Water quality monitoring is necessary throughout an ASR program. Objectives may vary, but they have included the following:

- Ensuring compliance of recovered water with federal and state drinking water standards

- Assessing the fate of disinfection by-products (DBPs), which are receiving a heightened level of attention under the Safe Drinking Water Act

- Evaluating the effect of geochemical reactions caused by interaction between recharged water, groundwater, and an aquifer matrix on the quality of the recovered water

- Identifying relationships between water quality and well performance

- Estimating the degree of mixing between recharged water and groundwater to evaluate the amount of recharged water recovered

### 5.6.1 Data Sources

A review of available literature was conducted to examine the resulting water qualities throughout the aquifer storage and recovery process. ASR pilot studies (Golder 2001; Golder 2004a) have been conducted in Yakima and Walla Walla, Washington. ASR has also been examined in Kennewick and the Palouse Basin (Aspect, 2004; Golder, 2005). These studies were used as the basis for the geochemical analysis of ASR in the Yakima Basin. Comprehensive surface water qualities for the Yakima River and drains at Moxee are available through the USGS. Representative water qualities for basalt aquifers in Washington were also obtained (Golder, 2004b).

### 5.6.2 Potential Concerns (including relevant chemical reactions)

#### *5.6.2.1 Water Quality*

Recharge water and groundwater mix in part by dispersion. During the period of recovery, the fraction of native groundwater is expected to increase as recovery proceeds. Most major ion concentrations are expected to increase during recovery because the TDS of groundwater is higher than that of the recharge water. Eventually, recovered water quality should be equivalent to that of the initial groundwater quality. In addition to dispersion, chemical reactions between aquifer solids and recharge water will affect the chemistry of recovered water. These reactions may include mineral precipitation/dissolution and cation exchange.

#### 5.6.2.2 Well Performance

Clogging of the well and the aquifer material is a common concern with ASR projects. Blockage of the pore space is dependent on the total suspended solids (TSS) in recharge water, groundwater and the resultant water quality. As little as 2 milligrams per liter (mg/L) of TSS can reduce the rate of recharge into the aquifer.

Mineral precipitation can also affect the efficiency of a well and permeability of the surrounding aquifer. When oxygen is introduced to the groundwater, oxide minerals may form if iron and manganese are present they may from oxides. These oxides can clog pore space and well screens, thus reducing the efficiency of the well.

Clay minerals can also affect well performance. Due to the flat platy structure of clay minerals, clay minerals are likely to bridge pore space causing a blockage of the flow. Kaolinite in particular is likely to cause this physical clogging of the aquifer. Changes in pH, cation chemistry or TDS can mobilize clay particles. Because of the nature of these materials, the reversal of the plugging once it has occurred is nearly impossible.

Biofouling is also considered as a potential concern. Differences in physiochemical conditions between groundwater and the water being recharged can increase the ability of the bacteria to thrive (*e.g.*, differences in temperatures, pH, and dissolved constituent concentrations). Disinfectant products can be used to reduce this concern. DBPs such as trihalomethanes (THM) and Haloacetic Acids (HAA) may form from the disinfection process. Case study data summarized in Pyne (1995) indicate that concentrations of THMs and HAAs decline relatively quickly when source water containing them is stored in the subsurface. The data generally suggest that THMs and HAAs are degraded biologically in a matter of weeks under anoxic groundwater conditions. The USGS documented little biological degradation of THMs within an aerobic shallow unconfined sand and gravel aquifer. One concern consistent in the studies is that residual chlorine in the source water (required by state regulation for public water systems) can react with organic matter in the aquifer with the potential to generate THMs. Whether the THMs generated then degrade appears to be a consequence of the groundwater redox conditions in the aquifer, with degradation occurring preferentially in anoxic aquifers.

### 5.6.3 Water Types

General water qualities are included in Table 5-4. Treated recharge water will likely be a calcium-sodium to calcium-magnesium bicarbonate water (Walla Walla). It will be oxidizing and slightly alkaline with a low TDS and parameters below drinking water standards.

### 5.6.4 Previous Examples

#### 5.6.4.1 Yakima- Ellensburg Formation

A pilot test to examine the feasibility of ASR in the Ahtanum-Moxee sub-basin in the central part of the Yakima basin was prepared for the City of Yakima in 2001 by Golder Associates (Golder, 2001). This study occurred in the Upper Ellensburg Formation, which is underlain by a clayey basalt. Water quality monitoring throughout the pilot test indicated compliance with drinking water standards. Although DBP concentrations did increase temporarily during storage before decreasing, DBP concentrations remained well below drinking water standards at all times. Based on the results of the tracer analyses, it is estimated that approximately 70 percent of the water recharged to the aquifer was recovered.

Field pH ranged from 6.1 to 7.7 and turbidity was low (0.29 to 0.46 NTU). Conductivity was also generally low. Over the period of storage, most major ion groundwater concentrations remained stable. By the third and final storage sampling events, the mixing of recharge water with native groundwater was evident for a number of constituents. Mixing during storage was most obvious for silicon, sodium and alkalinity.

The city of Yakima's ASR pilot testing using treated potable water documented initial increases in THM and HAA concentrations in the storage aquifer, and a corresponding decrease in residual chlorine, throughout the first half of the 55-day storage period between recharge and recovery. The increases were attributed to reaction of residual chlorine with naturally occurring organic matter in the groundwater. Concentrations of THMs and HAAs generally declined in the latter part of the storage period, and then declined rapidly in the recovered water during the recovery period. The declining concentrations were attributed to a combination of degradation and dilution/dispersion. THM and HAA concentrations remained well below drinking water criteria throughout the test (Golder, 2001).

#### *5.6.4.2 Walla Walla - Basalt*

The city of Walla Walla completed an ASR pilot test in 2002 in the confined basalt aquifer (Golder, 2004a). This aquifer is confined, permeable and bounded by faults or other low permeability structures in at least two directions. There are several areas of basalt (Grande Ronde, Wanapum and Saddle Mountain) that have different flow systems running through them. Each of these flows has the potential to have a different water quality.

In general the basalt water quality was found to be a calcium-sodium bicarbonate water (Table 5-4). When stored water was analyzed over the storage period, increases in pH, conductivity, redox potential, Ca, Mg, Si, Na, Mn, K $SO_4$, F, alkalinity and TDS were measured. A decrease in dissolved oxygen was observed. This is likely due to the recharge water trying to reach an equilibrium state with the groundwater. None of these parameters exceeded drinking water standards. Coliform bacterial was detected and exceeded the standard for the first two sampling events during the storage period. Other disinfection products were not detected.

A summary of whole rock geochemistry results (Table 5-5) show that there is a range of concentrations within each area of basalt. The basalt is primary $SiO_2$ averaging 52 to 55 percent of the rock chemistry. Aluminum and iron oxides make up about another forth of the material. CaO is also present at about 8 to 9 percent. The average and median concentrations of most parameters are within 15 percent of each other. Exceptions include Ba, Cr, Ni and Zr for the Saddle Mountains, Cr and Cu for the Wanapum and Cr for the Grande Ronde. While metals exist in the basalt, the mineralogical form they are contained in is significant in the availability of the metals to be released into solution. Unfortunately, mineralogical data is not available.

**TABLE 5-4**
**General Surface Water and Groundwater Quality**

| Water Quality | | EPA Drinking Water Standards[1] EPA-816-F-02-013 | Type[(a)] | Surface Water: Municipal Treated Water[2] | Groundwater: Confined Aquifer[2] | Groundwater: Well No 6[3] | Groundwater: Well 7[4] | Groundwater: Kennewick Regional Average[5] | | Groundwater: Wanapum[(b)] [6] |
|---|---|---|---|---|---|---|---|---|---|---|
| Location | | | | Yakima | Yakima | Walla Walla | City of Pullman | Saddle Mountain | Wanapum | |
| Formation | | | | - | Ellensburg | Basalt | Basalt | | | Basalt |
| **Parameter** | **Units** | | | | | | | | | |
| pH | s.u. | 6.5-8.5 | II | 6.14 to 7.3 | 7.3 | 8 | 7.4 | 7.7 | 7.4 | 7.5 |
| Temperature | °C | | | 4.6 to 8.1 | 22.5 | 21 | 18 | 65 (geothermal) | 60 (geothermal) | 17 |
| TDS | mg/L | | | 48 to 63 | 180 | - | - | 340.2 | 269.5 | - |
| TSS | mg/L | | | <5 | <2 | - | - | - | - | - |
| **Major Anions/Cations** | | | | | | | | | | |
| F | mg/L | 4.0/2.0 | I/II | <0.02 | 0.14 | 0.7 | <0.5 | 0.6 | 0.5 | 0.5 |
| Cl | mg/L | 250 | II | ~2 | 1.5 | 2.3 | <20 | 24 | 17 | 15 |
| $SO_4$ | mg/L | 250 | II | 4.9 to 5.8 | 3.9 | 5.5 | <10 | 53 | 29 | 30 |
| Ca | mg/L | | | <0.5 to 8.1 | 10.7 | 17.5 | 22 | 38 | 33 | 31 |
| Na | mg/L | | | <2.5 to 5.5 | - | 24 | 26 | 35 | 28 | 40 |
| K | mg/L | | | <5 | <5 | 5 | - | 6.9 | 4.9 | 5.1 |
| Mg | mg/L | | | <0.5 to 1.6 | 3.6 | 7.33 | 14 | 19 | 15 | 14 |
| **Nutrients** | | | | | | | | | | |
| $NO_3$ | mg/L-N | | | <0.02 | 0.4 | 0.01 | <0.5 | - | - | 2.9[(c)] |
| DOC | mg/L | | | - | - | - | - | - | - | - |
| TOC | mg/L | | | 0.086 to 1 | <0.35 | - | - | - | - | - |
| **Metals** | | | | | | | | | | |
| Total Al | | | | <0.2 | <0.2 | - | - | - | - | - |
| Dissolved Al | mg/L | 0.05 to 0.2 | II | 0.0068 to 0.014 | 0.0012 | - | - | - | - | - |
| Total Fe | mg/L | | | <0.1 | <0.1 | <0.05 | - | - | - | - |
| Dissolved Fe | mg/L | 0.3 | II | ~0.0068 | 0.018 | - | 0.4 | 0.03 | 0.03 | 0.05 |
| Total Mn | | | | <0.005 | <0.005 | 0.011 | - | - | - | - |
| Dissolved Mn | mg/L | 0.05 | II | ~0.00031 | 0.0024 | - | 0.04 | - | - | - |

**TABLE 5-4**
**General Surface Water and Groundwater Quality**

| Water Quality | | EPA Drinking Water Standards[1] EPA-816-F-02-013 | Type[(a)] | Surface Water: Municipal Treated Water[2] | Groundwater: Confined Aquifer[2] | Well No 6[3] | Well 7[4] | Kennewick Regional Average[5] | | Wanapum[(b)] [6] |
|---|---|---|---|---|---|---|---|---|---|---|
| Location | | | | Yakima | Yakima | Walla Walla | City of Pullman | Saddle Mountain | Wanapum | |
| Formation | | | | - | Ellensburg | Basalt | Basalt | | | Basalt |
| Redox | | | | | | | | | | |
| DO | mg/L | | | oxidizing | reducing | 0.2 | - | 4.5 | 5.2 | - |
| Disinfection Byproducts | | | | | | | | | | |
| THM | mg/L | 0.08 | | 0.0062 to 0.009 | - | <0.0002 | - | - | - | - |
| HAA | mg/L | 0.06 | | 0.014 to 0.027 | - | <0.000001 | - | - | - | - |

**Notes:**

(a) Primary (I) or secondary (II) maximum contaminant level (MCL).

(b) Detection limits were not available for Wanapum data.

"-" indicates the parameter was not included in the analysis.

**Source:**

[1] EPA, 2002. List of Drinking Water Contaminants and MCLs. EPA 816-F-02-013, July 2002.

[2] Golder Associates Inc., 2001. Aquifer Storage and Recovery (ASR) Pilot Test Results: Yakima, Washington Submitted to the City of Yakima, December 14, 2001.

[3] Golder Associates Inc., 2004(a). City of Walla Walla: Aquifer Storage and Recovery Pilot Testing Well No. 6 Submitted to the City of Walla Walla, January 28, 2004.

[4] Golder Associates Inc., 2004(b). Report on Well No. 3 Replacement Data Review and Well Siting Report. Submitted to the City of Pullman, January 13, 2004.

[5] Aspect Consulting, 2004. Aquifer Storage and Recovery Assessment, Coty of Kennewick WRIA Supplemental Water Storage Project. Prepared for WRIA 31 Planning Unit, October 24, 2005.

[6] Golder Associates Inc., 2005. Final Draft – Phase II – Level 1 Technical Assessment For the Palouse Basin (WRIA 34). Submitted to Palouse Watershed (WRIA 34) Planning Unit, February 2, 2005.

**TABLE 5-5**
**Whole Rock Chemistry for Several Basalt Types**

| | Saddle Mountains | | | | | Wanapun | | | | | Grande Ronde | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number of Analysis | Maximum | Minimum | Average | Median | Number of Analysis | Maximum | Minimum | Average | Median | Number of Analysis | Maximum | Minimum | Average | Median |
| Whole Rock Chemistry (%) | | | | | | | | | | | | | | | |
| $SiO_2$ | 41 | 59 | 47 | 52 | 52 | 12 | 54 | 50 | 52 | 52 | 76 | 57 | 52 | 55 | 55 |
| $Al_2O_3$ | 41 | 17 | 12 | 15 | 14 | 12 | 17 | 13 | 15 | 14 | 76 | 15 | 13 | 14 | 14 |
| FeO | 41 | 17 | 5.8 | 12 | 12 | 12 | 15 | 10 | 13 | 13 | 76 | 13 | 9.4 | 12 | 12 |
| MgO | 41 | 8.2 | 0.6 | 5.1 | 5.0 | 12 | 8.2 | 2.9 | 4.4 | 4.4 | 76 | 6.1 | 3.1 | 4.3 | 4.2 |
| CaO | 41 | 12 | 5.3 | 8.8 | 8.8 | 12 | 11 | 6.4 | 8.4 | 8.6 | 76 | 10 | 6.4 | 7.9 | 7.8 |
| $Na_2O$ | 41 | 4.1 | 2.0 | 2.6 | 2.5 | 12 | 3.4 | 2.4 | 2.9 | 2.9 | 76 | 3.5 | 2.8 | 3.1 | 3.1 |
| $K_2O$ | 41 | 3.5 | 0.3 | 1.2 | 1.2 | 12 | 2.0 | 0.4 | 1.3 | 1.3 | 76 | 2.4 | 0.6 | 1.5 | 1.5 |
| $TiO_2$ | 41 | 3.8 | 1.5 | 2.6 | 2.7 | 12 | 3.6 | 1.0 | 2.7 | 2.9 | 76 | 2.5 | 1.1 | 2.0 | 2.0 |
| $P_2O_5$ | 41 | 1.6 | 0.2 | 0.6 | 0.5 | 12 | 1.2 | 0.2 | 0.7 | 0.7 | 76 | 0.5 | 0.2 | 0.3 | 0.3 |
| MnO | 41 | 0.3 | 0.1 | 0.2 | 0.2 | 12 | 0.3 | 0.1 | 0.2 | 0.2 | 76 | 0.2 | 0.2 | 0.2 | 0.2 |
| Trace elements (parts per million) | | | | | | | | | | | | | | | |
| Ba | 41 | 4410 | 243 | 931 | 581 | 12 | 1043 | 175 | 673 | 639 | 76 | 844 | 367 | 600 | 582 |
| BaX | 40 | 4161 | 173 | 899 | 577 | 12 | 1001 | 135 | 637 | 611 | 45 | 873 | 0 | 584 | 614 |
| Co | 28 | 47 | 13 | 41 | 43 | 8 | 53 | 24 | 39 | 39 | 76 | 44 | 33 | 39 | 39 |
| Cr | 40 | 308 | 1.4 | 107 | 75 | 11 | 160 | 4.4 | 58 | 40 | 75 | 130 | 3.5 | 26 | 16 |
| Cs | 29 | 1.2 | 0.3 | 0.7 | 0.7 | 11 | 1.2 | 0.5 | 0.9 | 0.9 | 74 | 1.9 | 0.4 | 1.1 | 1.1 |
| Hf | 41 | 12 | 2.8 | 5.8 | 5.3 | 12 | 6.4 | 1.5 | 4.8 | 5.1 | 76 | 5.3 | 2.8 | 4.4 | 4.4 |
| NbX | 40 | 49 | 12 | 21 | 20 | 12 | 24 | 6.0 | 16 | 17 | 45 | 24 | 0 | 13 | 13 |
| Rb | 37 | 60 | 9.0 | 29 | 28 | 11 | 39 | 16 | 32 | 35 | 75 | 69 | 17 | 39 | 38 |
| RbX | 37 | 56 | 6.0 | 28 | 25 | 11 | 49 | 14 | 36 | 38 | 46 | 66 | 0 | 40 | 40 |
| SrX | 40 | 350 | 213 | 261 | 252 | 12 | 397 | 286 | 332 | 331 | 46 | 486 | 0 | 328 | 333 |
| Ta | 41 | 3.1 | 0.6 | 1.4 | 1.5 | 12 | 1.3 | 0.3 | 1.1 | 1.2 | 76 | 1.0 | 0.4 | 0.8 | 0.8 |
| Th | 41 | 8.9 | 1.4 | 4.5 | 4.1 | 12 | 5.5 | 0.4 | 4.0 | 4.0 | 76 | 7.3 | 1.9 | 4.6 | 4.3 |
| U | 38 | 2.1 | 0.5 | 1.1 | 1.1 | 11 | 1.7 | 0.5 | 1.2 | 1.2 | 30 | 1.8 | 0 | 1.2 | 1.2 |
| YX | 40 | 90 | 24 | 41 | 42 | 12 | 58 | 20 | 45 | 46 | 47 | 40 | 0 | 32 | 33 |
| Zn | 41 | 226 | 87 | 140 | 133 | 12 | 216 | 112 | 162 | 164 | 76 | 152 | 112 | 135 | 137 |
| Zr | 36 | 631 | 126 | 299 | 255 | 12 | 307 | 96 | 210 | 223 | 30 | 243 | 0 | 161 | 162 |
| Zrx | 40 | 546 | 120 | 247 | 219 | 12 | 260 | 68 | 203 | 213 | 46 | 231 | 0 | 174 | 179 |
| Sc | 41 | 40 | 23 | 32 | 31 | 12 | 40 | 31 | 36 | 36 | 76 | 38 | 29 | 34 | 34 |
| La | 41 | 74 | 15 | 34 | 34 | 12 | 37 | 7.6 | 28 | 30 | 76 | 30 | 16 | 22 | 21 |
| Ce | 41 | 149 | 31 | 68 | 68 | 12 | 82 | 16 | 57 | 58 | 76 | 59 | 31 | 45 | 45 |
| Nd | 41 | 87 | 18 | 37 | 35 | 12 | 50 | 13 | 35 | 36 | 76 | 37 | 18 | 27 | 27 |
| Sm | 41 | 19 | 4.0 | 8.0 | 8.1 | 12 | 12 | 2.7 | 8.1 | 8.5 | 76 | 8.0 | 3.8 | 6.3 | 6.4 |
| Eu | 41 | 5.4 | 1.3 | 2.5 | 2.1 | 12 | 3.4 | 1.0 | 2.5 | 2.5 | 76 | 2.3 | 1.3 | 1.9 | 1.9 |

**TABLE 5-5**
**Whole Rock Chemistry for Several Basalt Types**

| | Saddle Mountains | | | | | Wanapun | | | | | Grande Ronde | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Number of Analysis** | **Maximum** | **Minimum** | **Average** | **Median** | **Number of Analysis** | **Maximum** | **Minimum** | **Average** | **Median** | **Number of Analysis** | **Maximum** | **Minimum** | **Average** | **Median** |
| Gd | 41 | 18 | 4.2 | 8.0 | 8.1 | 12 | 12 | 3.6 | 8.4 | 8.8 | 30 | 20 | 4.5 | 6.7 | 6.3 |
| Tb | 41 | 2.7 | 0.7 | 1.2 | 1.2 | 12 | 1.9 | 0.6 | 1.3 | 1.4 | 75 | 1.4 | 0.8 | 1.1 | 1.1 |
| Yb | 41 | 9.1 | 2.3 | 4.0 | 3.8 | 12 | 5.7 | 2.1 | 4.3 | 4.6 | 76 | 3.9 | 1.9 | 3.2 | 3.2 |
| Lu | 41 | 1.4 | 0.35 | 0.6 | 0.6 | 12 | 0.9 | 0.35 | 0.7 | 0.7 | 76 | 0.6 | 0.41 | 0.5 | 0.5 |
| Cu | 35 | 112 | 5.0 | 47 | 42 | 10 | 106 | 15 | 44 | 36 | 28 | 62 | 0 | 29 | 30 |
| Ni | 34 | 203 | 2.7 | 65 | 47 | 10 | 117 | 1.0 | 38 | 34 | 28 | 20 | 0 | 12 | 11 |

Source:
Chemical Data for Flows and Feeder Dikes of the Yakima Basalt Subgroup, Columbia River Basalt Group, Washington, Oregon, and Idaho, and their Bearing on a Petrogenetic Model
By Thomas L. Wright, Margaret Mangan, And Donald A. Swanson U.S. Geological Survey Bulletin 1821

#### *5.6.4.3 Palouse - Basalt*

A Pullman-Moscow ASR program to store surface water in the ground during periods of low demand analyzed potential water quality changes (Golder, 2005). Surface water would be injected into one of two primary aquifers with the Palouse Basin: the Wanapum basalt aquifer or the Grande Ronde basalt aquifer (Golder, 2004b). Water quality data used in this geochemical modeling presented in Golder (2005) are in Table 5-4.

Mixing of surface water from the Palouse River and Paradise Creek with groundwater from the Grande Ronde and Wanapum aquifers was predicted to result in precipitation of only a few mineral phases. For both mixing models (Palouse River with Grande Ronde and Paradise Creek with Wanapum), precipitation of ferrihydrite was predicted. Ferrihydrite precipitation depends on the redox condition within the aquifer, which was not known with certainty. Mixing model results indicate that iron and manganese may exceed U.S. Environmental Protection Agency secondary drinking water standards in recovered water.

#### *5.6.4.4 Conclusions*

Resulting ASR water qualities are a combination of the recharging water quality and the groundwater quality. Other factors such as sediment chemistry and mineralogy, geothermal characteristics, redox conditions and secondary porosity will also affect the final water quality. Several of the studies provided above have used ASR successfully (Golder, 2004a). It is likely based on the basalt composition that this system will behave in a similar manner.

## 5.7 COSTS

The three major capital costs associated with a direct injection program include:

- Infrastructure associated with obtaining recharge water (e.g., surface water treatment facilities or river bank filtration wells)
- Transmission pipelines
- Injection wells

Additional costs are:

- Permitting
- Operations and maintenance
- Land acquisition for facilities
- Other

Only the major capital costs for direct injection projects are compiled. The primary permitting cost is compilation of supporting technical documentation that would likely include hydrogeological assessments, computer simulations, and pilot testing. The Yakima Basin groundwater model being developed by the USGS may be used, once developed, to realize cost efficiencies. Coordinating the permitting of multiple sites may also reduce permitting costs for individual project sites. Few direct injection permits have been processed in Washington State and the costs associated with permitting are not well-defined. The permitting cost of projects is expected to reduce significantly as more projects are processed over time, as the state gains more experience, and as the permitting process becomes more streamlined and better defined. Maintenance and operational costs are not compiled.

### 5.7.1 Unit Costs of Direct injection

Generalized capital costs have been developed. Cost estimates of higher confidence would require development of site-specific detailed estimates for each site. Assumed unit costs for the major capital components of direct injection are listed in Table 5-6 and are developed in the following sections.

#### *5.7.1.1 Infrastructure Associated with Obtaining Recharge Water*

Source water for direct injection is assumed to be the Yakima River during the winter (*i.e.*, October through March). Water quality for direct injection must be essentially potable quality in order to meet regulations protecting groundwater quality (WAC 173-200) and to minimize the potential for well clogging during injection. Two means of obtaining water of such quality are 1) a surface water drinking plant; and, 2) use of river bank filtration methods.

**TABLE 5-6**

**Assumed Unit Costs for Direct Injection**

| Item | Unit | Cost | Comment |
|---|---|---|---|
| Riverbank Filtration Well | Per well | $500,000 | Assumed depth of 100-150 feet. Cost includes pump, controls well house. |
| Surface Water Treatment | Per 1 mgd capacity | $1,000,000 | Cost assumes economy of scale for ~12 mgd capacity. |
| Transmission (urban) | Per mile | $1,000,000 | |
| Transmission (rural) | Per mile | $500,000 | |
| Injection Well | Per well | $2,000,000 | Assumed depth of 1,000-1,200 feet. Cost includes pump, controls well house. |
| Contingency | | 30% | Includes permitting. |

The cost of a surface water treatment plant is assumed to be on the order of $1M per million gallons per day (mgd) capacity. This unit cost is not linear, but is higher for small capacity plants (*e.g.*, 1 mgd), while economies of scale can provide a lower unit cost for large plants (*e.g.*, greater than 10 mgd). Each of the scenarios evaluated considers the recharge of approximately 12 mgd. Therefore a unit cost of $1M per mgd is considered conservatively high, and reasonable for the current level of effort, for a total of $12M for a 12 mgd capacity plant.

River bank filtration is often a more affordable alternative to a surface water treatment plant. The river bank filtration method uses wells to withdraw groundwater from aquifers adjacent to, and in close hydraulic continuity with, surface water. Hydrologically, it is effectively a surface water diversion. The natural filtration capability of the sediments can achieve the desired treatment of water for use in direct injection – the removal of suspended solids and pathogens. Department of Health guidelines suggest that wells that are at least 200 feet laterally away from surface water, or are greater than 50 feet deep below surface water, are adequately protective against pathogens in surface water that may enter groundwater wells, and do not need treatment as surface water.

The cost per well for a river bank filtration well is estimated to be on the order of $500,000. This is based on recent experience in other well construction projects. Variables considered in obtaining the cost include:

- Well specifications: 100 feet deep, 16-inch diameter, 2,000 gpm capacity.
- Drilling subcontractor costs.
- Wellhouse, pump and associated controls.
- Engineering fees.

A major assumption is the 2,000 gpm capacity of the source wells. This is dependent upon the transmissivity of the sediments in which the wells are completed and cannot be determined until the wells are installed and tested. Lower well capacities will require more wells to achieve the same total source capacity, whereas higher capacity wells will require fewer wells.

#### *5.7.1.2 Transmission Pipelines/Distribution System Upgrades*

The cost of transmission pipelines varies significant between installation in urban areas or in rural areas. The cost of installation in urban areas is assumed to be on the order of $1M per mile, and is based on recent construction bids for the City of Yakima (personal communication, Mr. Dave Brown of the city of Yakima). The cost in rural areas is assumed be half of this (i.e., $500,000 per mile).

#### *5.7.1.3 Direct Injection Well Costs*

The cost of direct injection wells is assumed to on the order of $2M per well. This assumes the following variables:

- Well specifications: 1,000-feet, 16-inch diameter, 2,000 gpm capacity.
- Drilling subcontractor costs.

- Wellhouse, pump and associated controls.
- Engineering fees.

Costs may vary according to the following factors:

- Flowing artesian conditions may increase the cost.
- Actual depth of the well may vary, and will directly affect costs (*i.e.*, a deeper well will cost more).
- Well recharge capacity will directly affect overall costs (*e.g.*, lower well recharge capacity will require additional wells to achieve the same cumulative recharge volume).
- Property acquisition is not considered. Well sites (either river bank filtration or direct injection wells) require a one-acre property to satisfy the requirement of the Washington State Department of Health 100-foot sanitary setback around wellheads for potable supply wells. A total of 16 separate wells are considered. Because many of the wells will be located in rural areas, the cost per well site is expected to be minimal.

In certain areas, existing wells may be available for use in a direct injection program and preclude the need for as many new wells dedicated to direct injection. Municipal systems may be able to make some wells of their systems available for direct injection during the winter, when demand is low and may be satisfied with fewer well. Irrigation wells are not used during the winter. These wells would likely require minor require modifications to accommodate direct injection, but the cost of such modifications would be significantly less than a new well (e.g., modification of the City of Yakima's Kissel well was less than $50,000). Additionally, well construction details of the wells would have to be confirmed to ensure that meet permitting requirements (e.g., state well construction regulations [WAC 173-160], and state and federal underground injection control regulations [WAC 173-218]). Some examples of existing wells that may be considered for a future direct injection program are:

- The city of Yakima has three deep municipal supply wells, one of which has already been retro-fitted for direct injection, and is planning to install new deep wells with the capability to be used for direct injection.

- The city of Ellensburg is planning to install several deep aquifer wells along the alignment identified for direct injection wells in this project.

- Irrigation wells in the Blackrock-Moxee area – a survey of existing candidate wells in this has not been conducted.

### 5.7.2 Site Specific Costs

Site-specific construction costs are estimated for each of the direct injection sites. Numbers have been rounded. Cost per acre foot considers only the volume of water that allows the increase of Yakima River flow in the six months from April through September – additional stream flow augmentation will occur outside of this period. The cost per acre foot is calculated only for the scenario for each injection site that provides the maximum benefit – other scenarios discussed previously in this chapter that provide lower levels of streamflow augmentation are not tabulated in this section. Table 5-7 provides an overview of the streamflow benefits from direct injection.

**TABLE 5-7**

**Summary of Direct Injection Benefits**

(all sites assume an injection rate of 6,400 AF over six months [e.g., April-September]; maximum benefit to TWSA for each site is highlighted in bold)

| Recovery Style | Application | Increase in TWSA | Comments |
|---|---|---|---|
| **AHTANUM** | | | |
| Active | Replace municipal summer surface water diversion | 6,000 AF | Some seepage back to the Yakima River |
| | Pump & dump (direct streamflow augmentation) | 6,000 AF | Improves temperature, turbidity and other water quality parameters. |
| | Satisfying future municipal demand | 2,700 AF | Assumes 55% consumptive use. |
| Passive | Seepage of injected water back to the Yakima River | 1,400 AF | 3,200 AF when equilibrium is reached between injection and seepage. Increased groundwater storage. |
| **Intermittent Active** | **Replace municipal summer surface water diversion during water short years** | **>6,000** (e.g., 18,000 AF if actively recovered after 5 years of injection) | **Active recovery only in water-short years.** |
| **KITTITAS** | | | |
| Active | Replace irrigation surface water diversion – delivery to the Town and/or Cascade irrigation canals | 6,000 AF | Some seepage back to the Yakima River |
| | Pump & dump (direct streamflow augmentation) | 6,000 AF | Improves temperature, turbidity and other water quality parameters. |
| | Satisfying future municipal demand | 2,400 AF | Assumes 60% consumptive use. |
| Passive | Seepage of injected water back to the Yakima River | 1,400 AF (after 10 years) | 3,200 AF when equilibrium is reached between injection and seepage. Increased groundwater storage. |
| **Intermittent Active** | **Replace irrigation surface water diversion – delivery to the Town and/or Cascade irrigation canals** | **>6,000** (e.g., 18,000 AF if actively recovered after 5 years of injection) | **Active recovery only in water-short years.** |

| Recovery Style | Application | Increase in TWSA | Comments |
|---|---|---|---|
| **BLACKROCK-MOXEE** | | | |
| Active | Replace irrigation surface water diversion – delivery to the Roza irrigation canal | 6,000 AF | Some seepage back to the Yakima River |
| | Pump & dump (direct streamflow augmentation) | 6,000 AF | Improves temperature, turbidity and other water quality parameters. |
| Passive | | Not quantified. | 3,200 AF when equilibrium is reached between injection and seepage. Increased groundwater storage. Extends/restores the sustainability of depleted groundwater resources. Detailed quantitative analysis has not been conducted. The lag time between injection and realizing quantitative seepage may be significant (e.g., >100 years) |
| **Intermittent Active** | **Replace irrigation surface water diversion – delivery to the Roza irrigation canal** | **>6,000** (e.g., 18,000 AF if actively recovered after 5 years of injection) | **Active recovery only in water-short years.** |

#### *5.7.2.1 Ahtanum Valley Direct Injection Costs*

The principal needs for implementing a direct injection program in the Ahtanum Valley are:

- Use of the city of Yakima's Naches River Surface water Treatment plant
- Upgrade of possibly eight miles of transmission system,
- Installation of four injection/recovery wells

Active recovery of injected water on an annual basis provides the maximum increased availability of water to replace current municipal surface water diversions by the City of Yakima during the six month period of April through September (6,000 AF). A summary of costs is presented in Table 5-8.

**TABLE 5-8**

**City of Yakima (Ahtanum Valley) Direct Injection Costs**

| Item | Unit | Unit Cost | Quantity | Total |
|---|---|---|---|---|
| Transmission (urban) | Per mile | $1,000,000 | 8 | $8,000,000 |
| Injection Wells | Per well | $2,000,000 | 4 | $8,000,000 |
| **Subtotal cost** | | | | $16,000,000 |
| Contingency (30%) | | | | $4,800,000 |
| **Total Cost** | | | | $20,800,000 |
| **Streamflow benefit April-Sept. from active recovery to replace current municipal surface water diversion** (acre feet) | | | | 6,000 |
| **Cost Per Acre Foot** | | | | $3,500 |

### *5.7.2.2 Kittitas Valley Direct Injection Costs*

The principal needs for implementing a direct injection program in the Kittitas Valley are:

- Use of the city of Ellensburg's Ranney-type City Wells as a source of water for direct injection
- Construction of a 12 mgd capacity surface water treatment plant
- Use of the city of Ellensburg's transmission system
- Installation of four injection/recovery wells

Active recovery of injected water on an annual basis provides the maximum increased availability of water to replace current irrigation surface water diversions to the Town and Cascade irrigation canals during the six month period of April through September (6,000 AF). A summary of costs is presented in Table 5-9.

**TABLE 5-9**

**City of Ellensburg (Kittitas Valley) Direct Injection Costs**

| Item | Unit | Unit Cost | Quantity | Total |
|---|---|---|---|---|
| Treatment plant | 1 mgd | $1,000,000 | 12 | $12,000,000 |
| Injection Wells | Per well | $2,000,000 | 4 | $8,000,000 |
| **Subtotal cost** | | | | $20,000,000 |
| Contingency (30%) | | | | $6,000,000 |
| **Total Cost** | | | | $26,000,000 |
| **Streamflow benefit April-Sept. from active recovery to Town and/or Cascade irrigation canals to replace current surface water diversion** (acre-feet) | | | | 6,000 |
| **Cost Per Acre Foot** | | | | $4,300 |

#### *5.7.2.3 Blackrock-Moxee Direct Injection Costs*

The principal needs for implementing a direct injection program in the Kittitas Valley are:

- Installation of four river bank filtration wells next to the Yakima River to supply water for direct injection
- Construction of a transmission line approximately eight miles long
- Installation of four injection/recovery wells

Active recovery of injected water on an annual basis provides the maximum increased availability of water to replace current irrigation surface water diversions to the Rosa irrigation canal during the six month period of April through September (6,000 acre feet). A summary of costs is presented in Table 5-10.

**Table 5-10**

**Blackrock-Moxee Direct Injection Costs**

| Item | Unit | Unit Cost | Quantity | Total |
|---|---|---|---|---|
| Riverbank Filtration Well | Per well | $500,000 | 4 | $2,000,000 |
| Transmission (rural) | Per mile | $500,000 | 8 | $4,000,000 |
| Injection Wells | Per well | $2,000,000 | 4 | $8,000,000 |
| **Subtotal cost** | | | | $14,000,000 |
| Contingency (30%) | | | | $4,200,000 |
| **Total Cost** | | | | $18,200,000 |
| **Streamflow benefit April-Sept. from active recovery to Rosa irrigation canal to replace current surface water diversion** (acre feet) | | | | 6,000 |
| **Cost Per Acre Foot** | | | | $3,000 |

# 6.0 REFERENCES


Aspect Consulting. 2004. Aquifer Storage and Recovery Assessment, Coty of Kennewick WRIA Supplemental Water Storage Project. Prepared for WRIA 31 Planning Unit, October 24, 2005.

Barnett, D.B. 2000. Groundwater monitoring and tritium-tracking plan for the 200 area state-approved land disposal site: U.S. Department of Energy, Report number PNNL-13121.

Biggane, J. 1982. The Low-Temperature Geothermal Resource and Stratigraphy of Portions of Yakima County, Washington. Washington State University, College of Engineering Research Report 82/15-7. Report prepared for Washington State Department of Natural Resources.

Brown, Dave. 2007. Personal email communication from Dave Brown, city of Yakima Water/Irrigation Division Manager to Chris Pitre, Golder Associates, regarding Diurnal Curve for Municipal Supply with an added question. September 13, 2007.

Cearlock, D.B., C.R. Cole, H. P. Foote, and R.W. Wallace. 1975. Mathematical Ground-Water Model of the Ahtanum-Moxee Subbasins, Yakima County, Washington. Report for Department of Ecology, State of Washington. Battelle Pacific Northwest Laboratories.

Colorado State University. 2005. SDF View, Streamflow Depletion Factor Model. Available online at http://www.ids.colostate.edu/index.html?/projects/sdfview/ [Accessed Sept. 13, 2007].

Conover, C. S. 1954. Ground-water conditions in the Rincon and Mesilla Valleys and adjacent areas in New Mexico: U.S. Geol. Survey Water-Supply Paper 1230, 200 p. [1955].

Cooke, Ted. 2004. Government Decision-Making: Rate-Setting Decisions. Water/Climate Briefing: Central Arizona Project, Presentation to Decision Center for a Desert City, Global Institute of Sustainability at Arizona State University. Available: http://dcdc.asu.edu/dcdcmain/detail.php?cid=18,26,28&ID=95.

Diebold, D.B., Buchanan, J.P., Durham, F.E. 1995. Hydrogeology of the Northeastern Columbia Plateau: the Wanapum and Grande Ronde hydrostratigraphic units in Lincoln and Spokane Counties, Washington: Washington Department of Ecology, Abstracts for the Symposium on the Hydrology of Washington.

Economic and Engineering Services (EES), Montgomery Water Group, Inc., R.C. Bain & Associates and McKenzie Consulting. 2003. Watershed Management Plan, Yakima River Basin. Yakima River Basin Watershed Planning Unit and Tri-County Water Resources Agency. January 2003.

EPA. 2002. List of Drinking Water Contaminants and MCLs. EPA 816-F-02-013, July 2002.

Foxworthy, B.L. 1962. Geology and Groundwater Resources of the Ahtanum Valley, Yakima County, Washington. U.S. Geological Survey Water Supply Paper 1598, United States Government Printing Office, Washington, D.C.

Glover, R. E. 1960. Ground water-surface water relationships [A paper given at Ground Water Section of Western Resources Conference, Boulder, Colorado]: Colorado State Univ. paper CER60REG45, 8 pp. [1961].

Glover, R. E., and Balmer, C. G. 1954. River depletion resulting from pumping a well near a river: Am. Geophys. Union Trans., v. 35, pt. 3, p. 468-470.

Golder Associates Inc. 2000a.. Technical Compilation Aquifer Storage and Recovery (ASR) Pilot test. Report to the City of Yakima. Prepared by Golder Associated, Redmond, Washington. August, 2000. Project #983-1085-001.6000.

Golder Associates Inc. 2000b. Pilot Test Plan for an Aquifer Storage and Recovery Program. Report to the City of Yakima. Prepared by Golder Associated, Redmond, Washington. August, 2000. Project #983-1085-001.6000.

Golder Associates Inc. 2001. Aquifer Storage and Recovery (ASR) Pilot Test Results: Yakima, Washington Submitted to the City of Yakima, December 14, 2001.

Golder Associates. 2002. Naches Basin (WRIA 38) Storage Assessment. Prepared for the Yakima River Basin Planning Unit on behalf of the City of Yakima.

Golder Associates Inc. 2004(a). City of Walla Walla: Aquifer Storage and Recovery Pilot Testing Well No. 6. Submitted to the City of Walla Walla, January 28, 2004.

Golder Associates Inc. 2004(b). Report on Well No. 3 Replacement Data Review and Well Siting Report. Submitted to the City of Pullman, January 13, 2004.

Golder Associates Inc. 2005. Final Draft – Phase II – Level 1 Technical Assessment For the Palouse Basin (WRIA 34). Submitted to Palouse Watershed (WRIA 34) Planning Unit, February 2, 2005.

Hansen, A.J., Jr., J. J., Vaccaro, and H. H. Bauer. 1994. Groundwater Flow Simulation of the Columbia Plateau Regional Aquifer System, Washington, Oregon, and Idaho. Water Resources Investigations Report 91-4187.

Hantush, M. S. 1964. Hydraulics of wells, in Chow, Vente, ed., Advances in Hydroscience, v. 1: New York, Academic Press, p. 386.

Hantush, M. S. 1965. Wells near streams with semipervious beds: Jour. Geophys. Research, v. 70, no. 12, p. 2829-2838.

Harbargh, A.W., Banta, E.R., Hill, M.C., and McDonald, M.G. 2000. MODFLOW-2000. The U.S. Geologic Survey Modular Ground-Water Model-User Guide to Modularization Concepts and the Ground-Water Flow Process. U.S. Geological Survey Open-File report 00-92.

Jenkins, C.T. 1968. Computation of Rate and Volume of Stream Depletion by Wells. U.S. Geological Survey Techniques of Water Resources Investigations, D1-4.

Jones, M.A., Vaccaro, J.J., and Watkins, A.M. 2006. Hydrogeologic framework of sedimentary deposits in six structural basins, Yakima River Basin, Washington: U.S. Geologic Survey Scientific Investigations Report 2006-5116, 24 pp.

Massmann, Joel W. 2003. A Design Manual for Sizing Infiltration Ponds. Final Research Report Research Project Agreement No. Y8265 Implementation of Infiltration Ponds Research. Prepared for Washington State Transportation Commission Department of Transportation and in cooperation with U.S. Department of Transportation Federal Highway Administration October 2003.

Office of Financial Management (OFM). 2007. Official April 1, 2007 Population Estimates. June 27, 2007. Available http://www.ofm.wa.gov/pop/april1/default.asp.

Pyne, R.D. 1995. Groundwater Recharge and Wells: A Guide to Aquifer Storage and Recovery. Lewis Publishers, Boca Raton. 376 p.

Rumbaugh, J. and D Rumbaugh. 1999. Guide to Using Groundwater Vistas. Environmental Simulations Inc.

Sonnichson, Roger. 2007. Personal communication. Email with Historical RiverWare data.

Theis, C. V. 1941. The effect of a well on the flow of a nearby stream: Am. Geophys. Union Trans., v. 22, pt. 3, p. 734-738.

Theis, C. V., and Conover, C. S. 1963. Chart for determination of the percentage of pumped water being diverted from a stream or drain, in Bentall, Ray, compiler, Shortcuts and special problems in aquifer tests: U.S. Geol. Survey Water-Supply Paper 1545-C pp. C106-Cl09 [1964].

U.S. Bureau of Reclamation (Reclamation). 2002. Interim Comprehensive Basin Operating Plan for the Yakima Project, Washington. U.S. Bureau of Reclamation. November 2002.

U.S. Geological Survey (USGS). 1999. Washington Land Cover Dataset. Edition 1. U.S. Geological Survey: Sioux Falls, SD USA.

U.S. Geological Survey (USGS). Water Quality Data. http://waterdata.usgs.gov/nwis.

Vaccaro, J.J. and T.D. Olsen. 2007. Estimates of Ground-Water Recharge to the Yakima River Basin Aquifer System, Washington, for Predevelopment and Current Land-Use and Land-Cover Conditions. U.S. Geological Survey Scientific Investigations Report 2007–5007.

Washington Department of Transportation (WSDOT). 2006. Highway Runoff Manual M 31-16 Engineering and Regional Operations Division, Environmental and Engineering Programs Headquarters Environmental Affairs and Hydraulics. PT 06-033.

WASY GmbH Berlin. 1991. FEFlow User Manual – An interactive graphics-based finite-element simulation system.

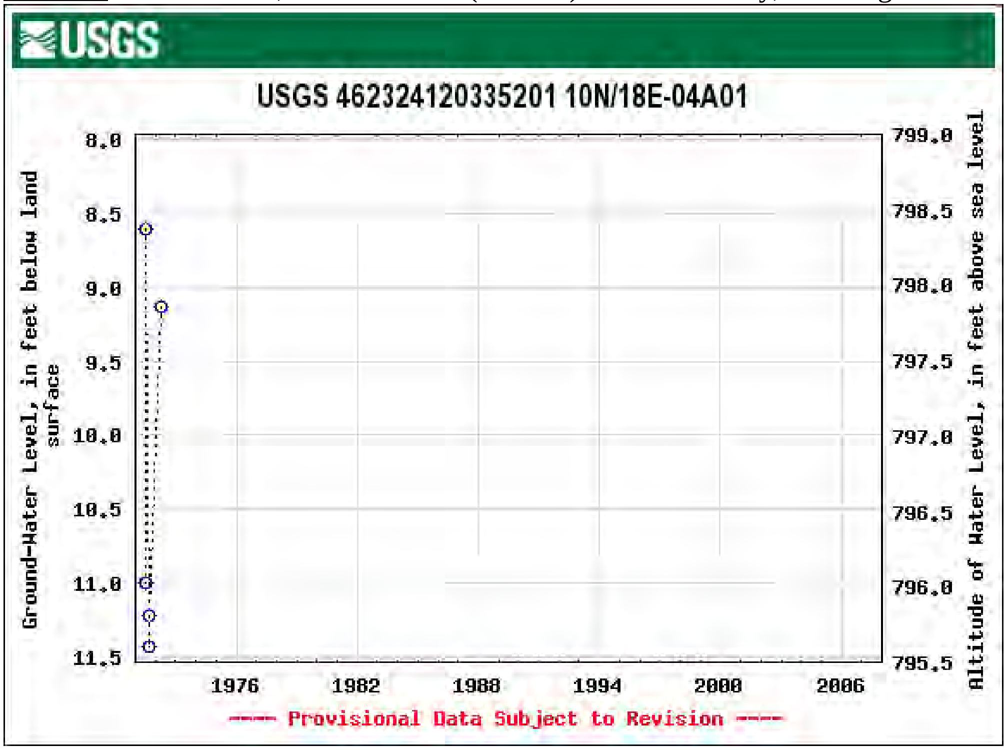
Western Regional Climate Center (WRCC). 2007. Washington Monthly Average Pan Evaporation (Inches). Available: http://www.wrcc.dri.edu/htmlfiles/westevap.final.html#WASHINGTON.

Whiteman, K. J., J. J. Vaccaro, J. B. Gonthier, and H. H. Bauer. 1994. The hydrogeologic framework and geochemistry of the Columbia Plateau Aquifer System, Washington, Oregon, and Idaho. Professional Paper 1413-B.

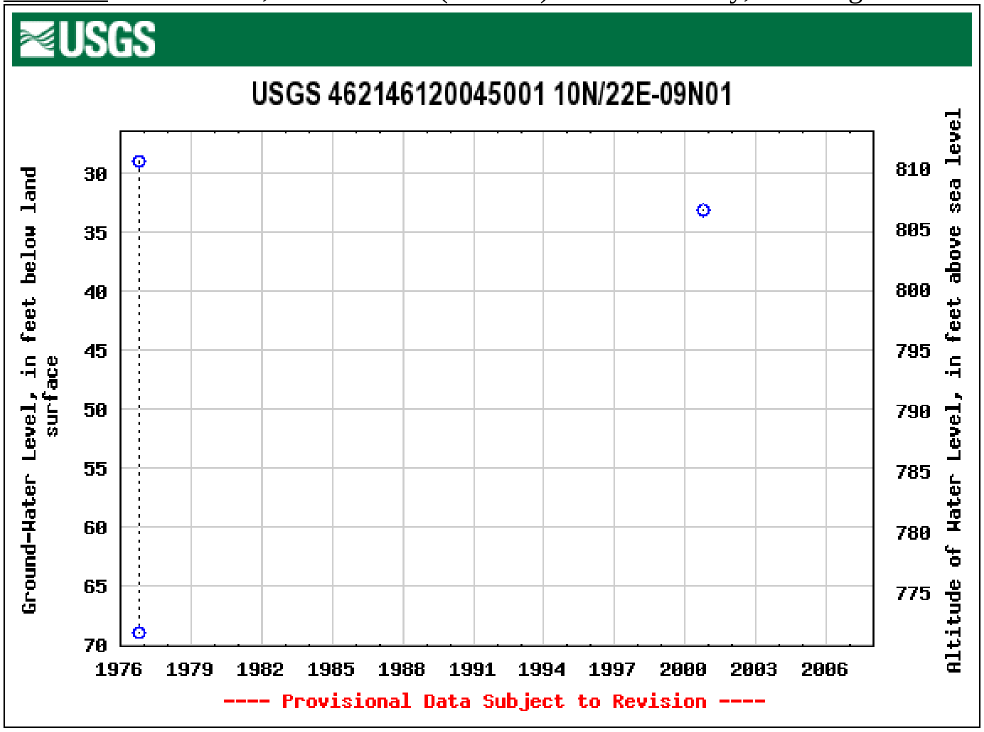
# APPENDIX A

## UNCONSOLIDATED AND CONSOLIDATED SEDIMENTARY AQUIFERS

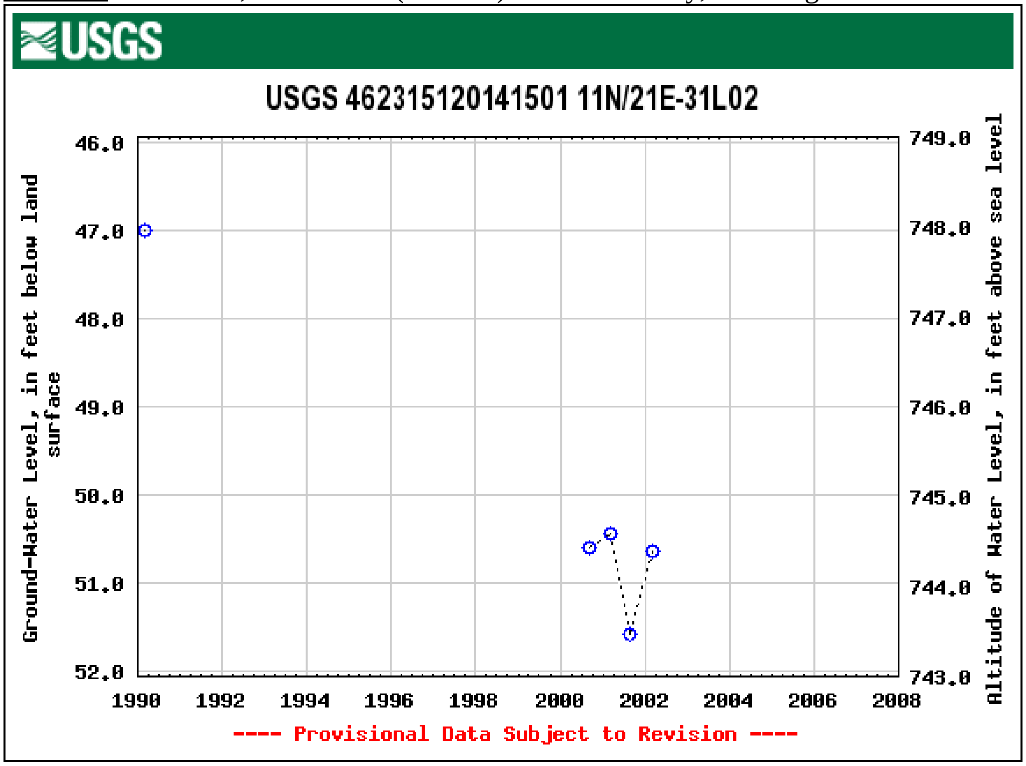
Aquifer unit: Quaternary Alluvium, 18 feet bgs
Location: 46°23'24.61", 120°33'53.06" (NAD27) Yakima County, Washington



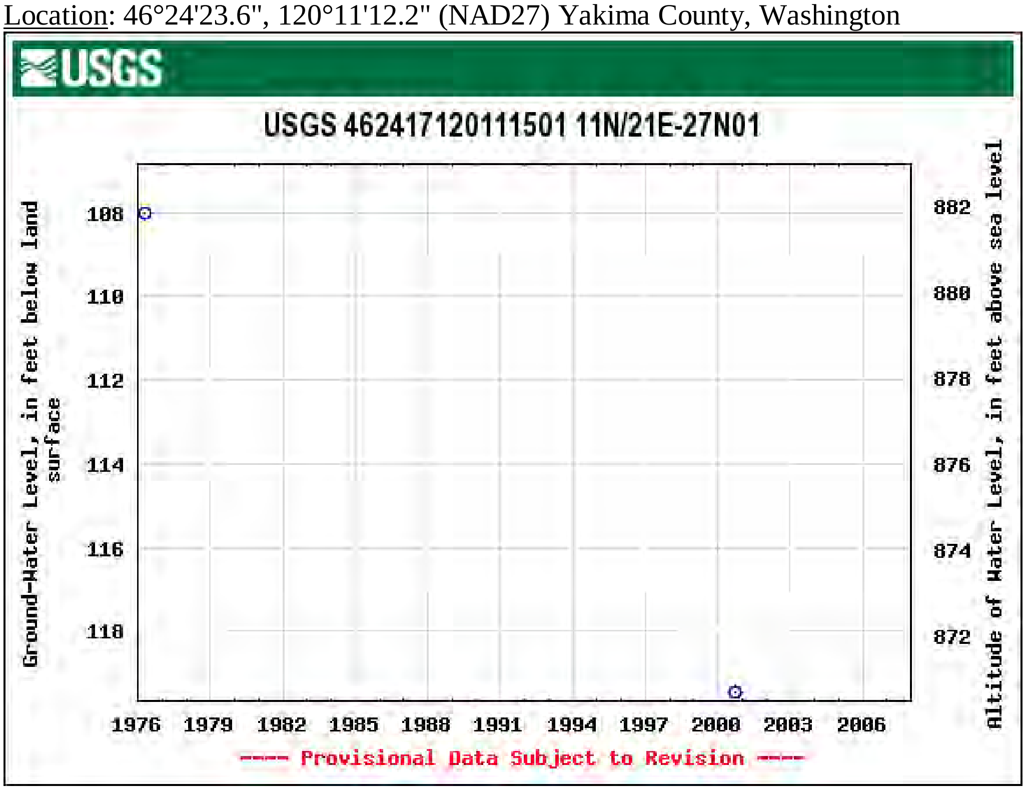

Aquifer unit: Unclassified Overburden, 158 feet bgs
Location: 46°21'49.3", 120°04'39.9" (NAD27) Yakima County, Washington



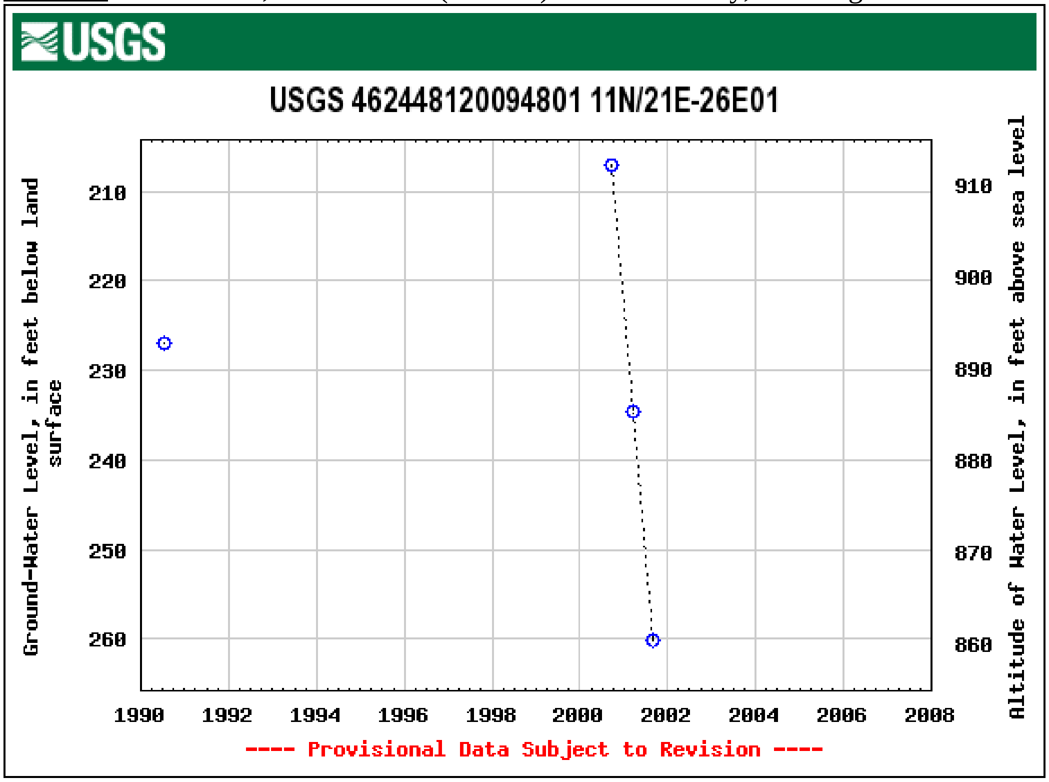
Aquifer unit: Unclassified Overburden, 143 feet bgs
Location: 46°23'37", 120°14'40" (NAD27) Yakima County, Washington



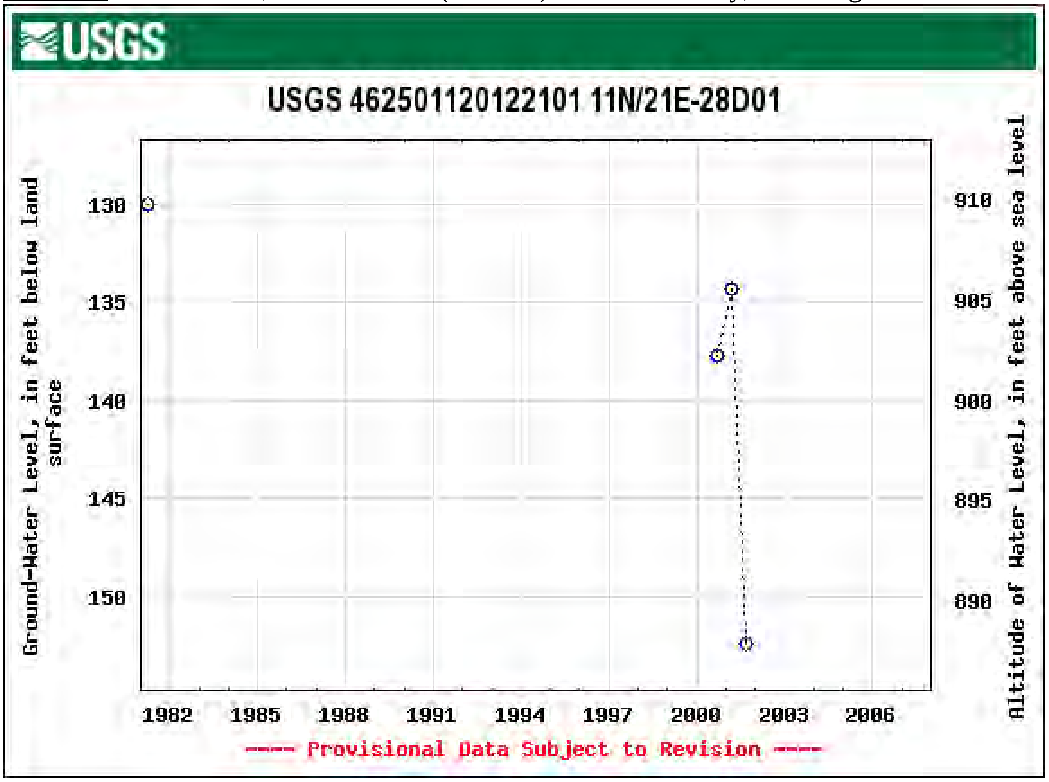

Aquifer unit: Unclassified Overburden, 343 feet bgs
Location: 46°24'23.6", 120°11'12.2" (NAD27) Yakima County, Washington



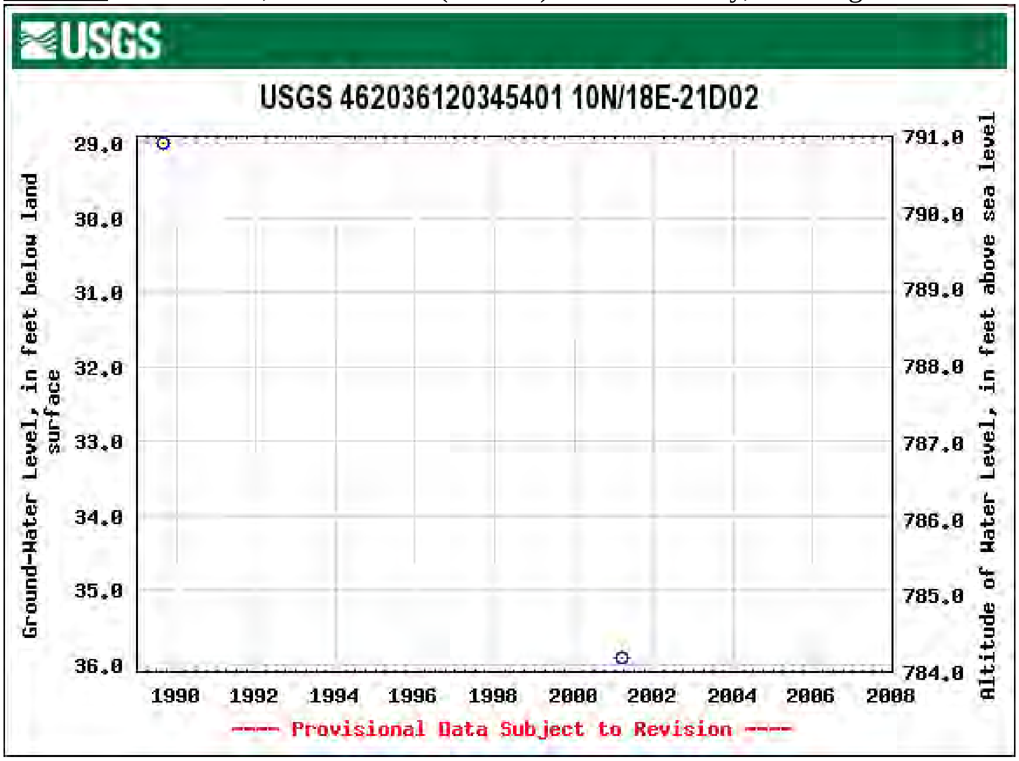
Aquifer unit: UNCLASSIFIED OVERBURDEN, 360 feet bgs
Location: 46°24'48.1", 120°09'55.3" (NAD27) Yakima County, Washington



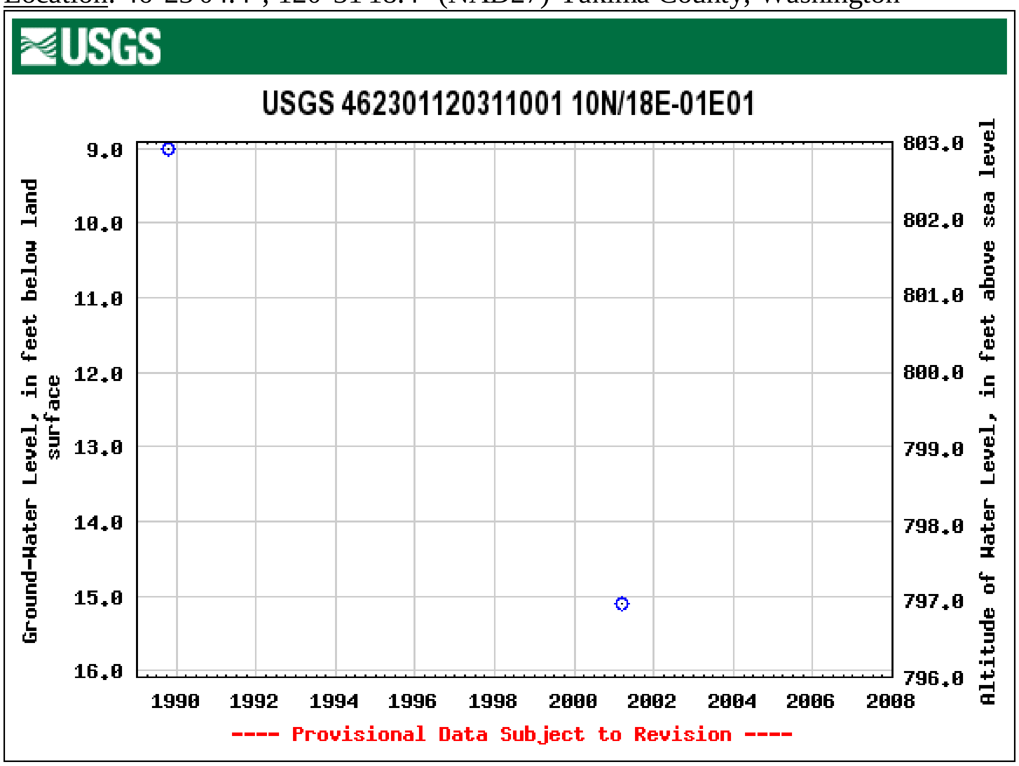

Aquifer unit: UNCLASSIFIED OVERBURDEN, 357 feet bgs
Location: 46°25'07.7", 120°12'25.5" (NAD27) Yakima County, Washington



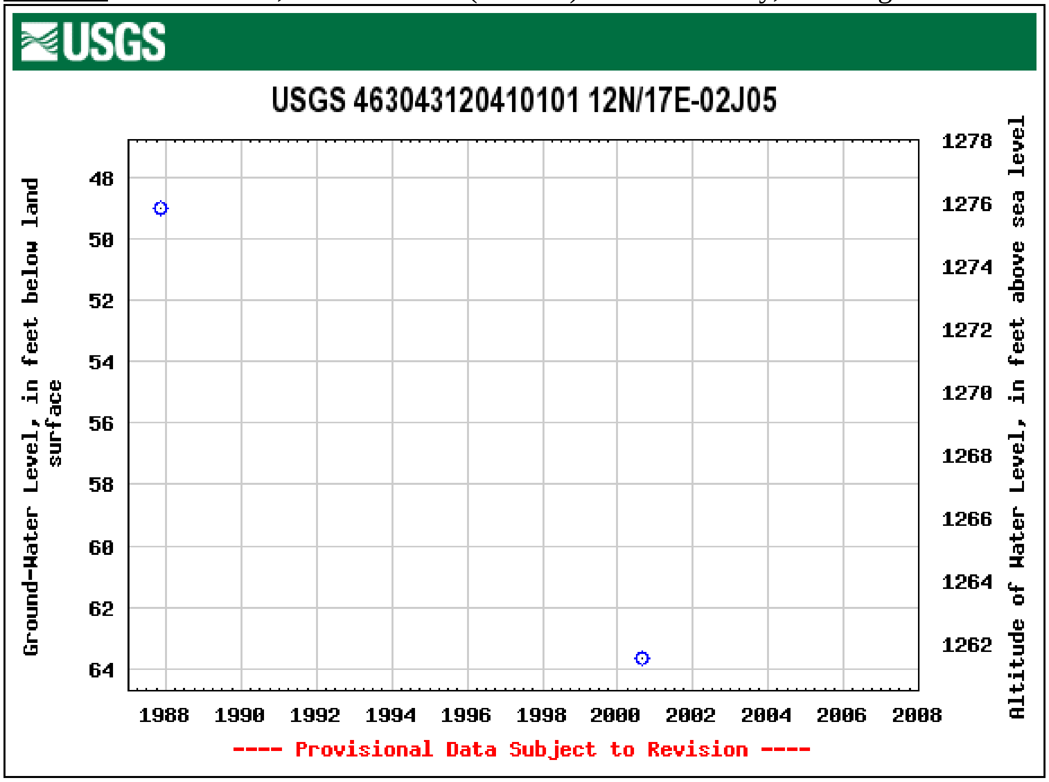
Aquifer unit: Unclassified Overburden, 78 feet bgs
Location: 46°20'45.1", 120°34'56.3" (NAD27) Yakima County, Washington



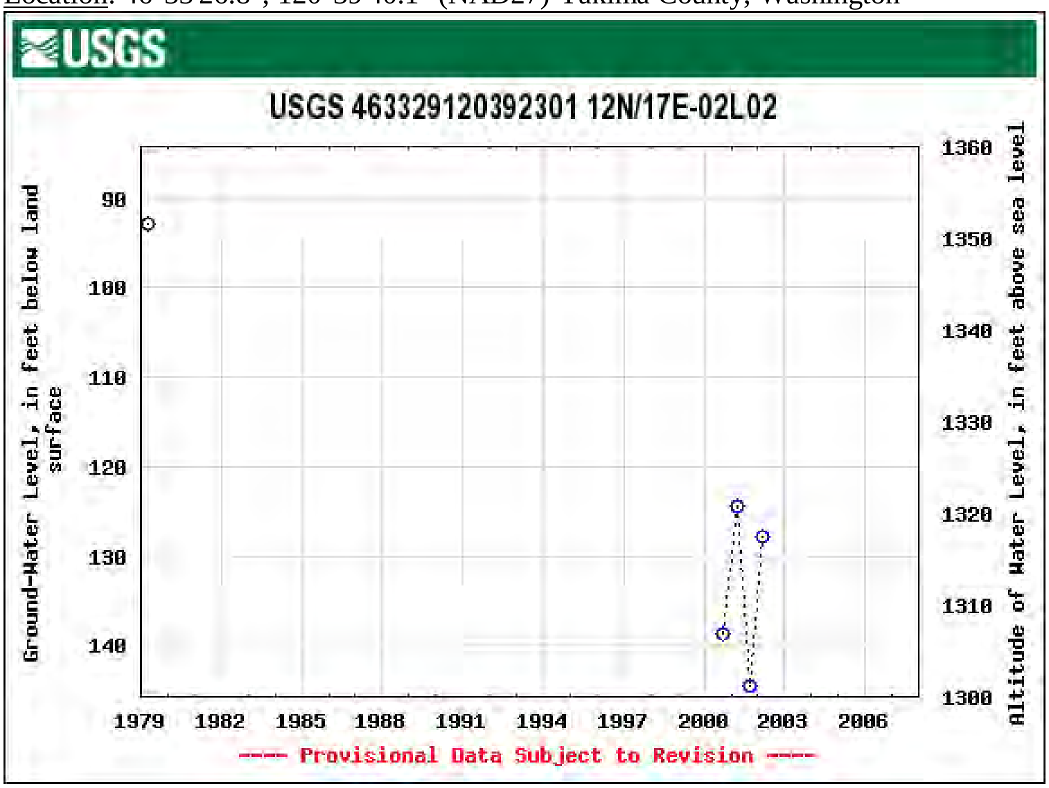

Aquifer unit: Unclassified Overburden, 100 feet bgs
Location: 46°23'04.4", 120°31'18.4" (NAD27) Yakima County, Washington



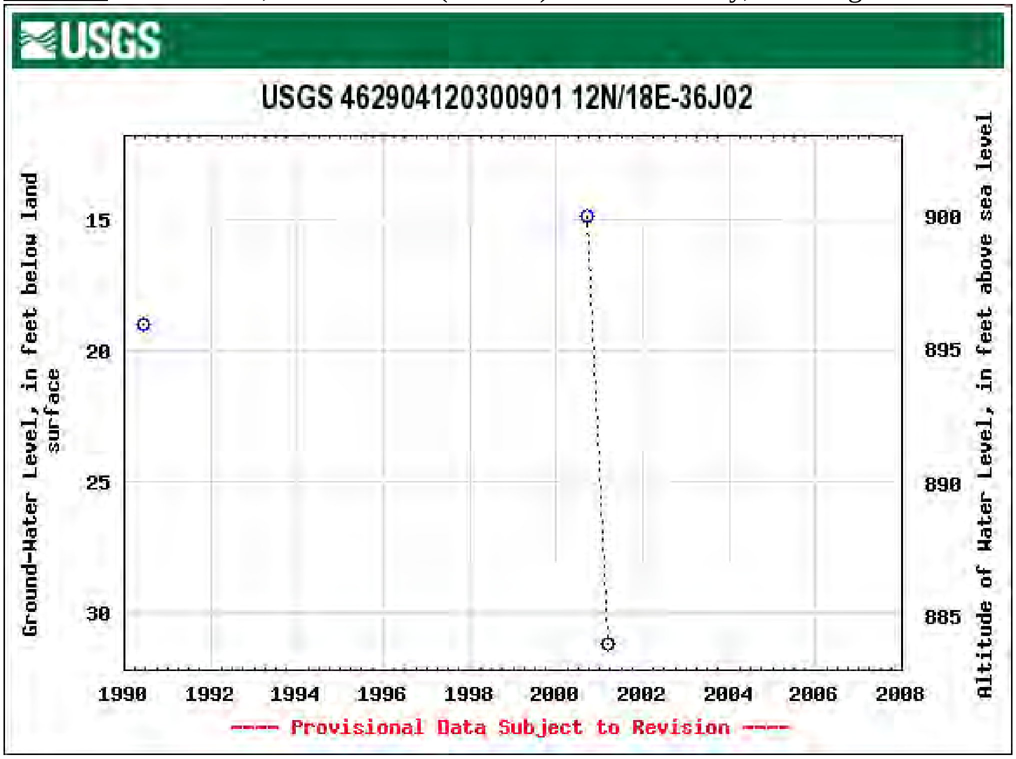
Aquifer unit: Unclassified Overburden, 180 feet bgs
Location: 46°33'17.66", 120°39'03.18" (NAD27) Yakima County, Washington



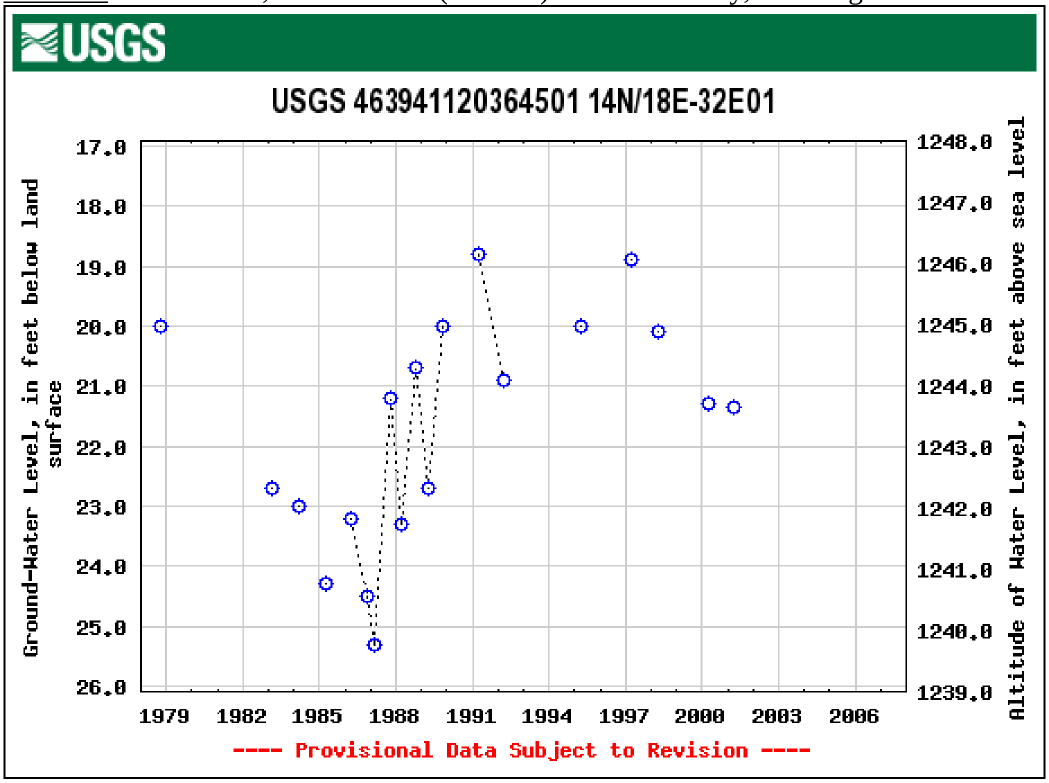

Aquifer unit: Unclassified Overburden, 434 feet bgs
Location: 46°33'26.8", 120°39'40.1" (NAD27) Yakima County, Washington



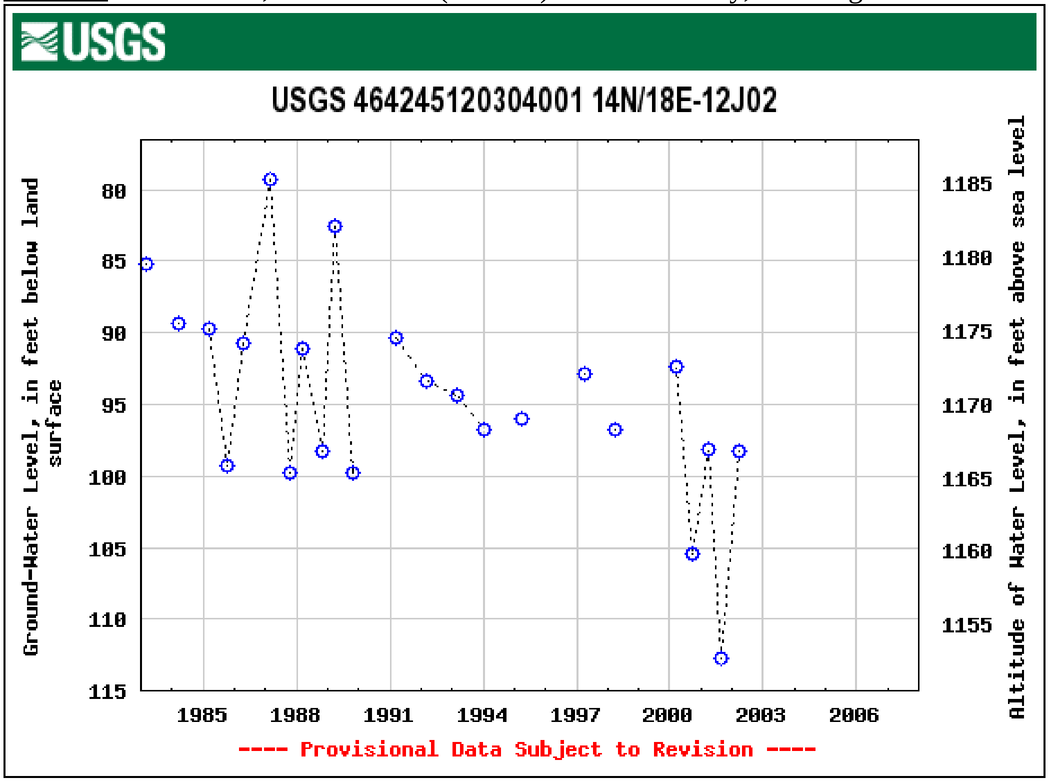
Aquifer unit: Unclassified Overburden, 79 feet bgs
Location: 46°29'02.7", 120°30'08.0" (NAD27) Yakima County, Washington



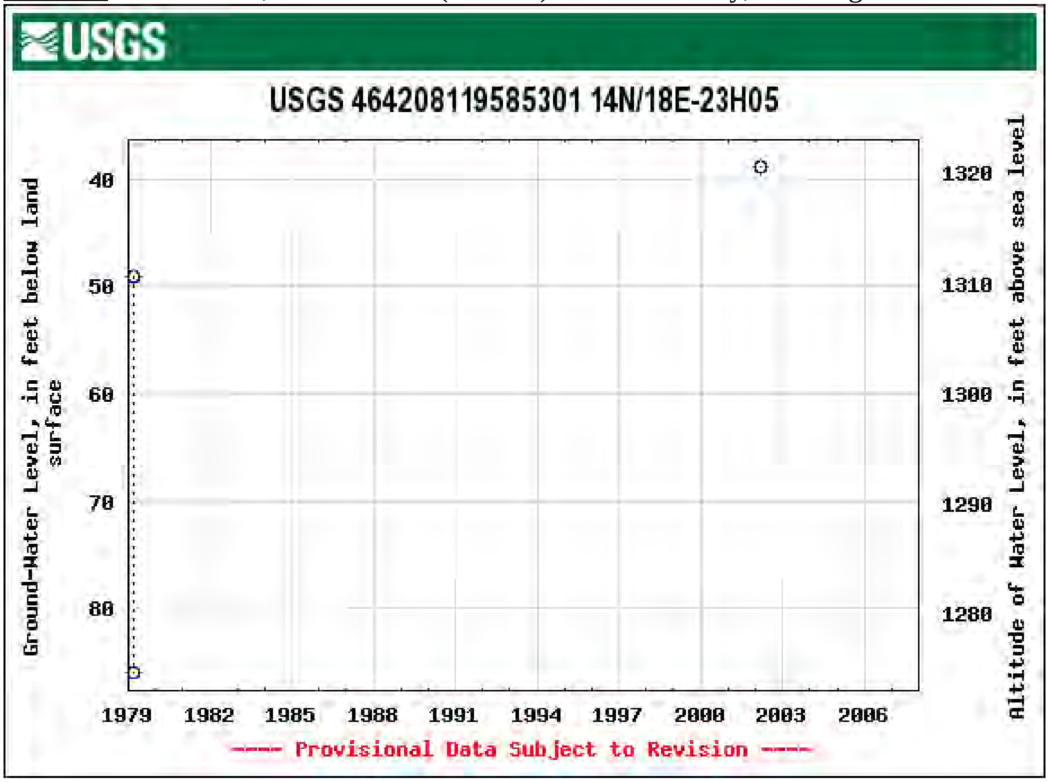

Aquifer unit: Ellensburg Formation, 80 feet bgs
Location: 46°39'39.6", 120°36'45.8" (NAD27) Yakima County, Washington



Aquifer unit: Ellensburg Formation, 290 feet bgs
Location: 46°42'57.9", 120°30'39.2" (NAD27) Yakima County, Washington




Aquifer unit: Unclassified Overburden, 90 feet bgs
Location: 46°41'16.4", 120°31'50.2" (NAD27) Yakima County, Washington



Aquifer unit: Unclassified Overburden, 184 feet bgs
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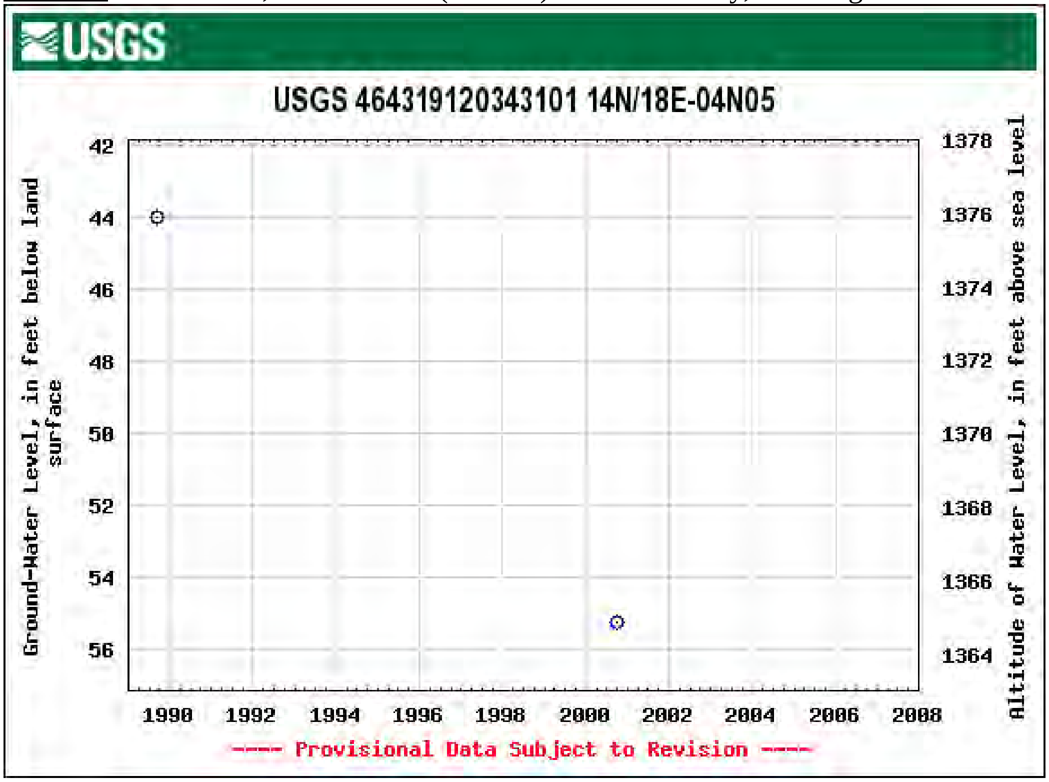
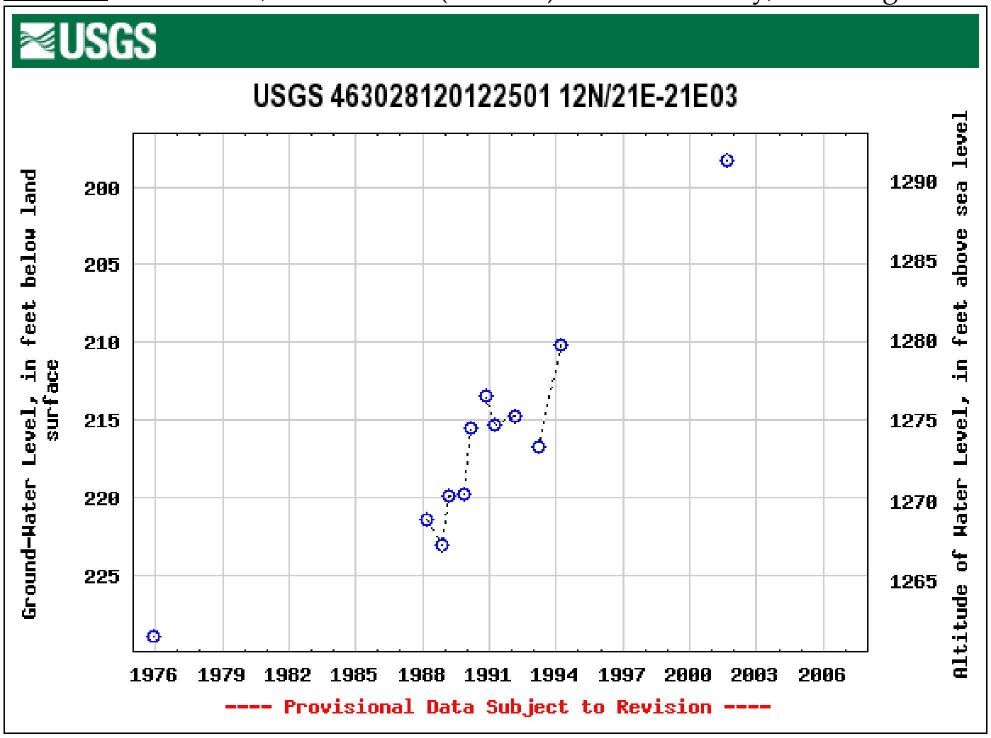
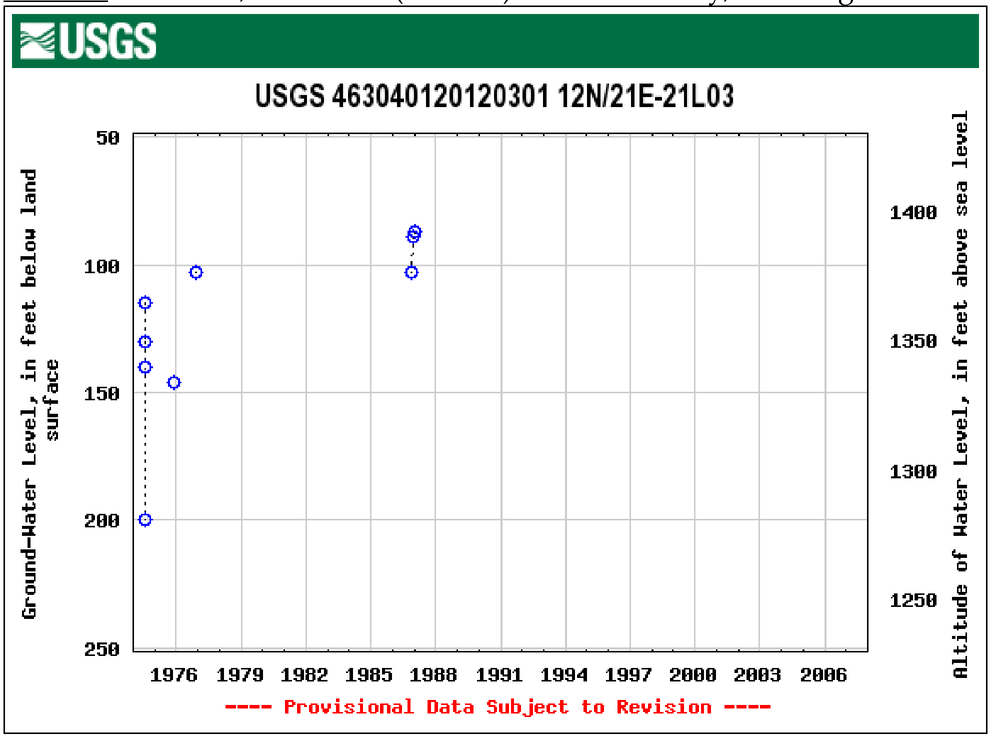


**BASALT AQUIFERS**

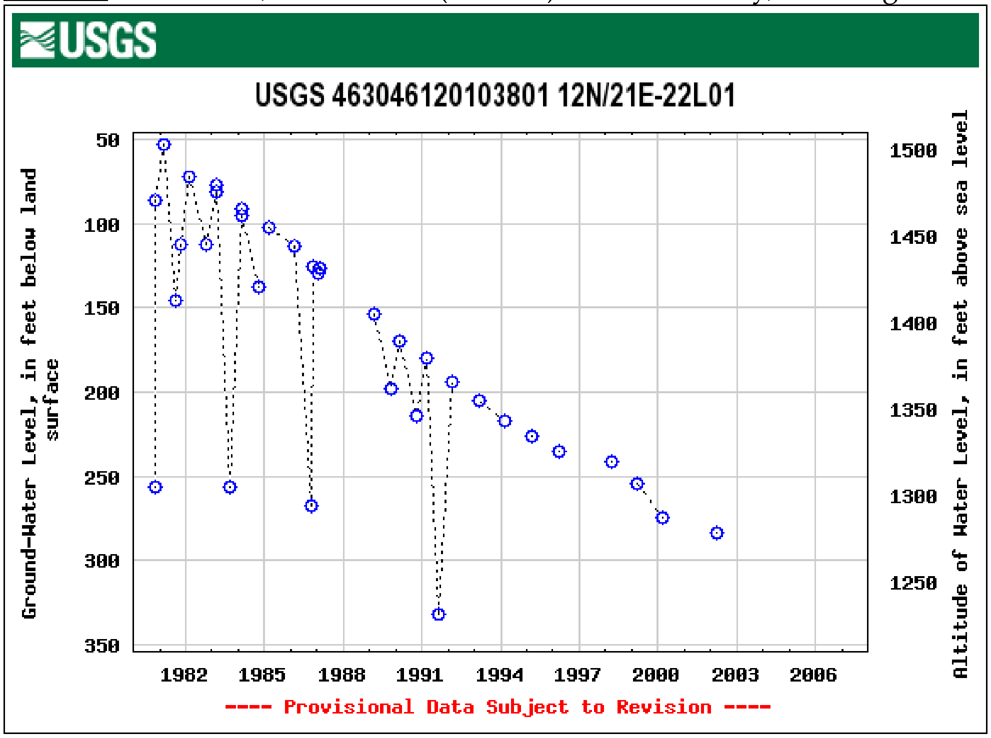
Aquifer unit: Columbia River Basalt Group, 384 feet bgs
Location: 46°30'50.7", 120°12'21.4" (NAD27) Yakima County, Washington



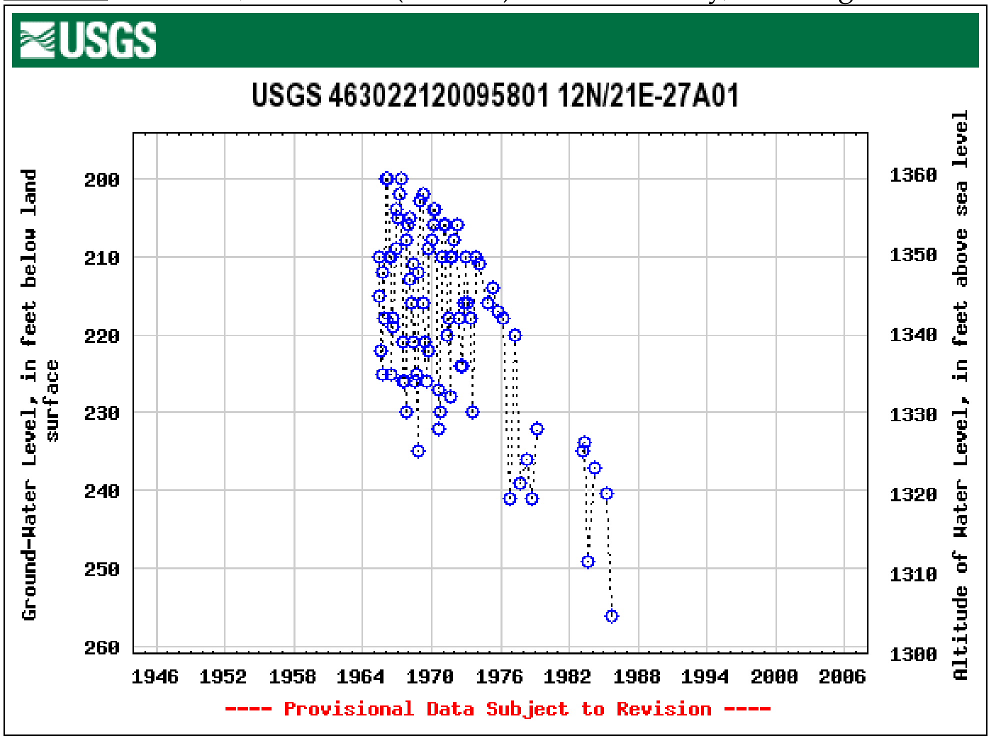

Aquifer unit: SADDLE MNT BASALT , 448 feet bgs
Location: 46°30'40", 120°12'03" (NAD27) Yakima County, Washington



Aquifer unit: Wanapum Basalt, 662 feet bgs
Location: 46°30'47.0", 120°10'36.8" (NAD27) Yakima County, Washington




Aquifer unit: Saddle Mnt Basalt, 295.5 feet bgs
Location: 46°30'20", 120°09'59" (NAD27) Yakima County, Washington



Aquifer unit: Saddle Mnt Basalt Of Yakima, 965 feet bgs
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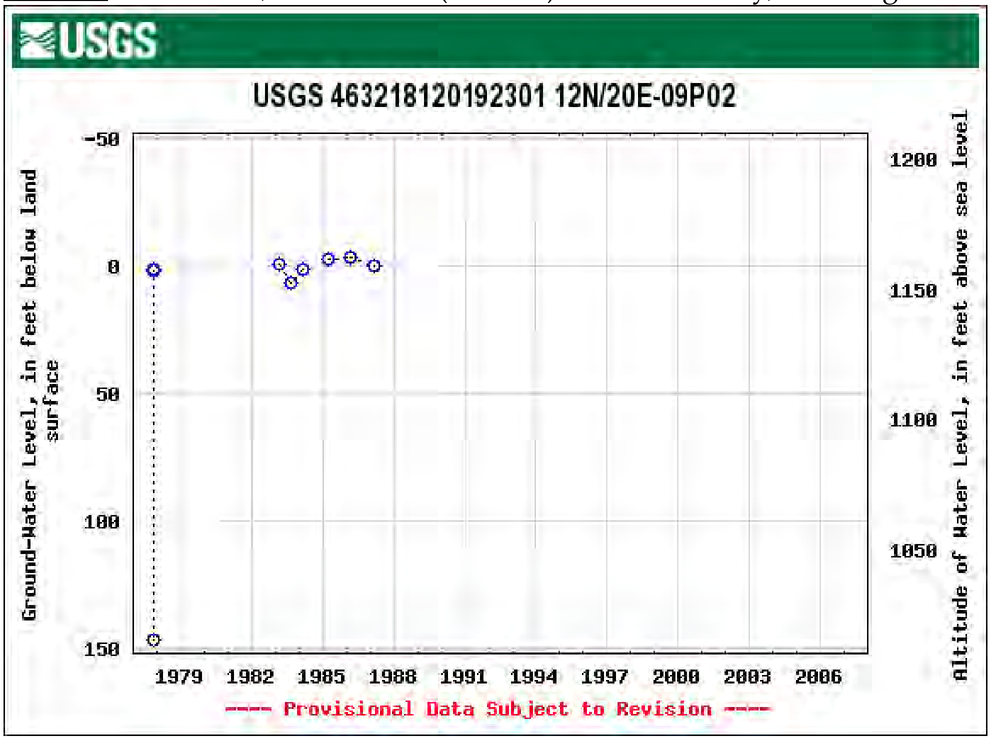
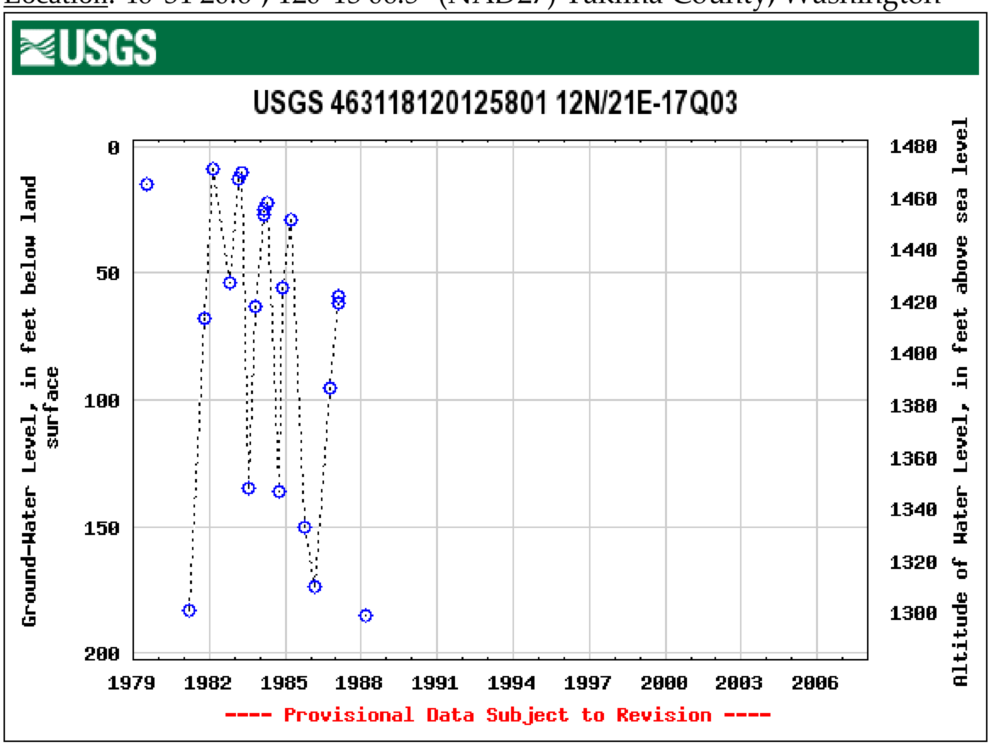
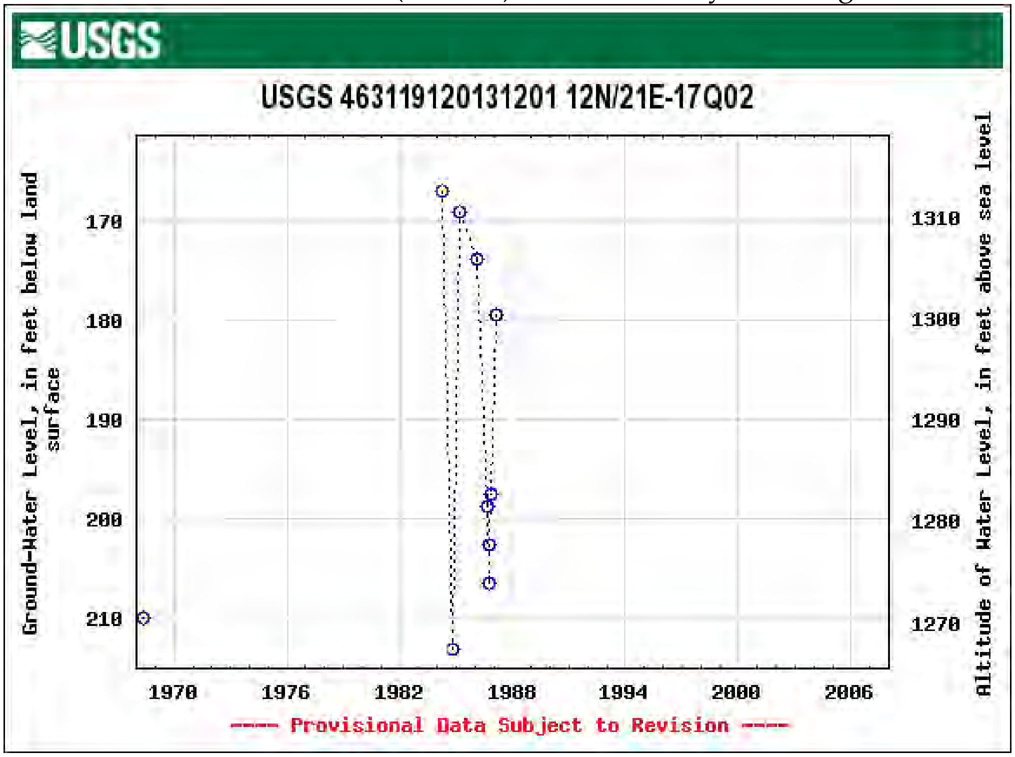



Aquifer unit: Wanapum Basalt, 1,550 feet bgs
Location: 46°31'20.6", 120°13'06.5" (NAD27) Yakima County, Washington



Aquifer unit: Saddle Mnt Basalt, 800 feet bgs
Location: 46°31'19", 120°13'12" (NAD27) Yakima County, Washington



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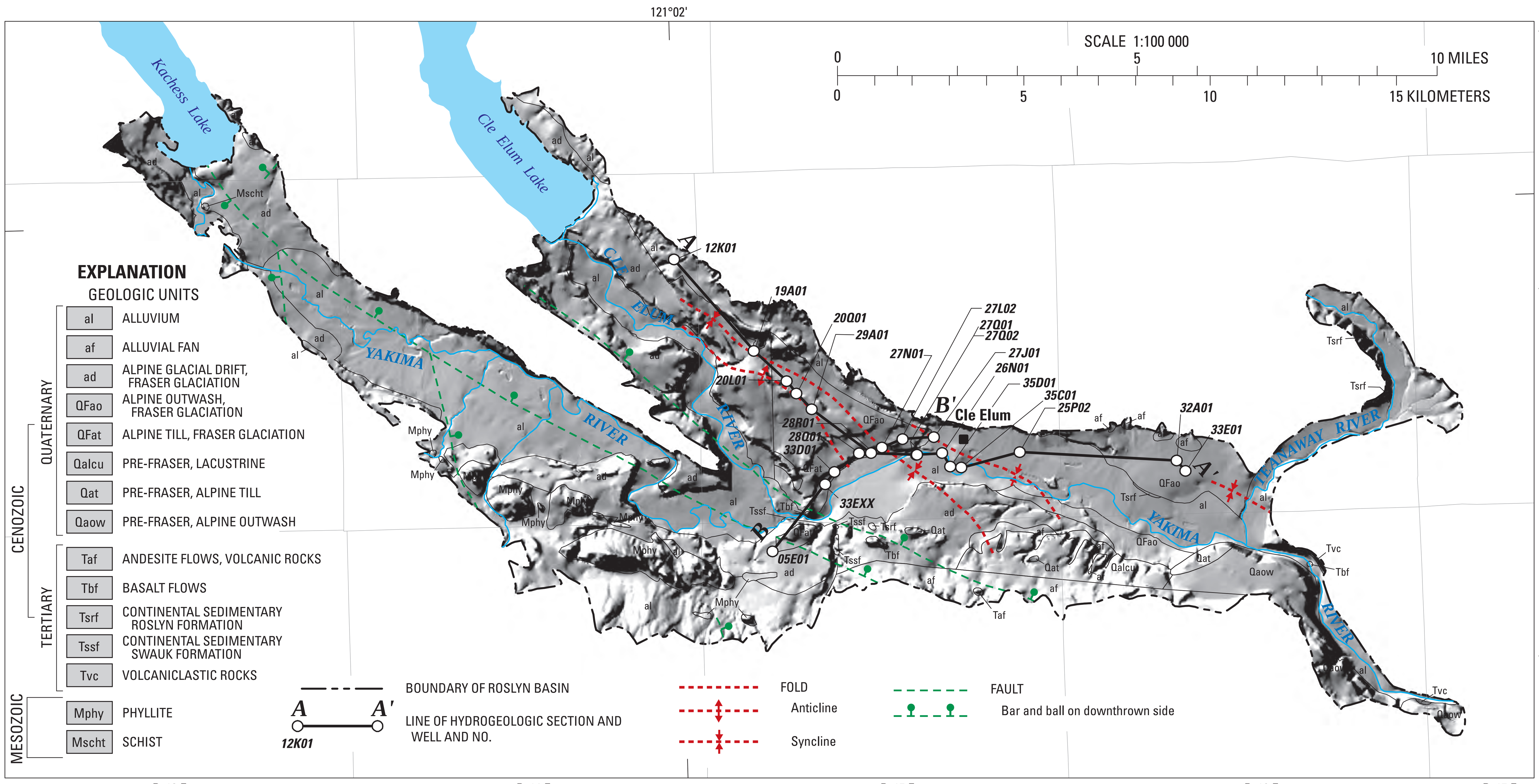


Base from U.S. Geological Survey and/or
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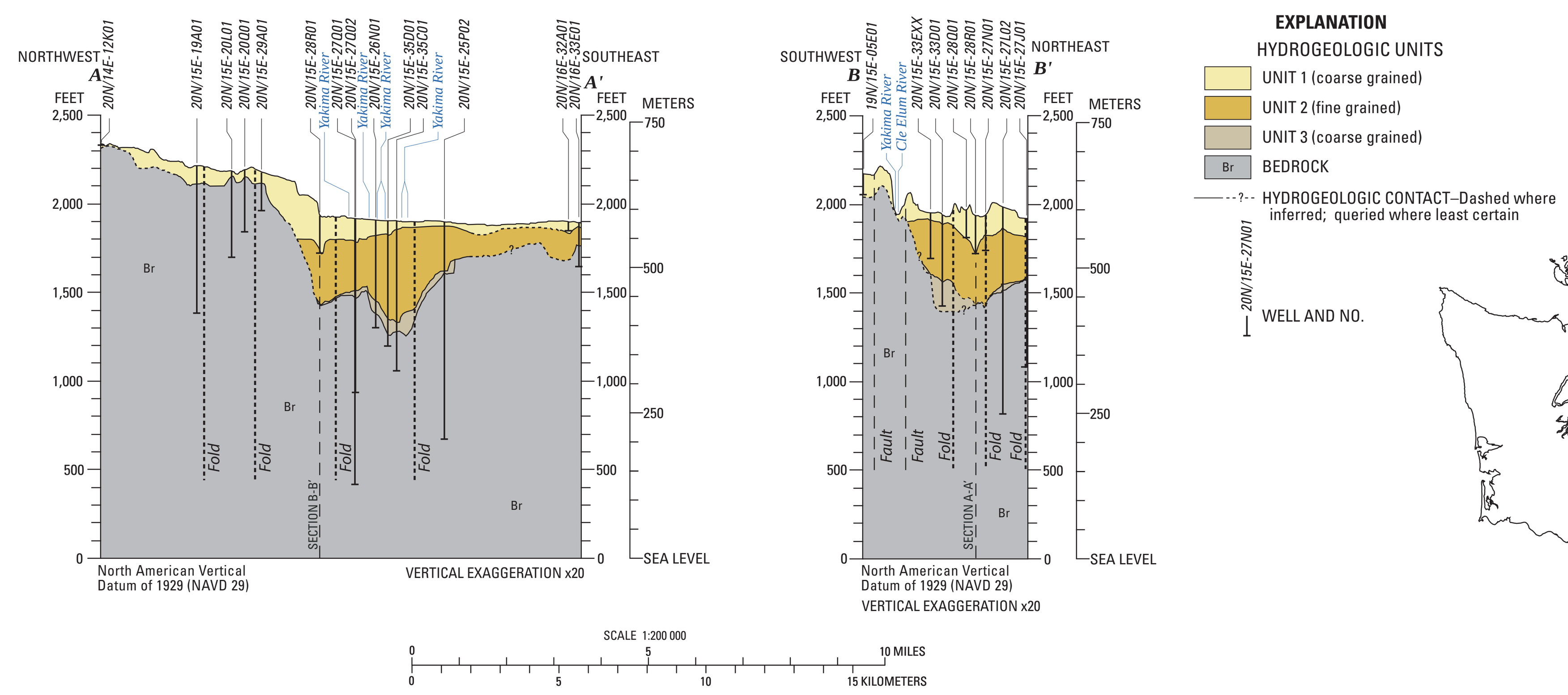
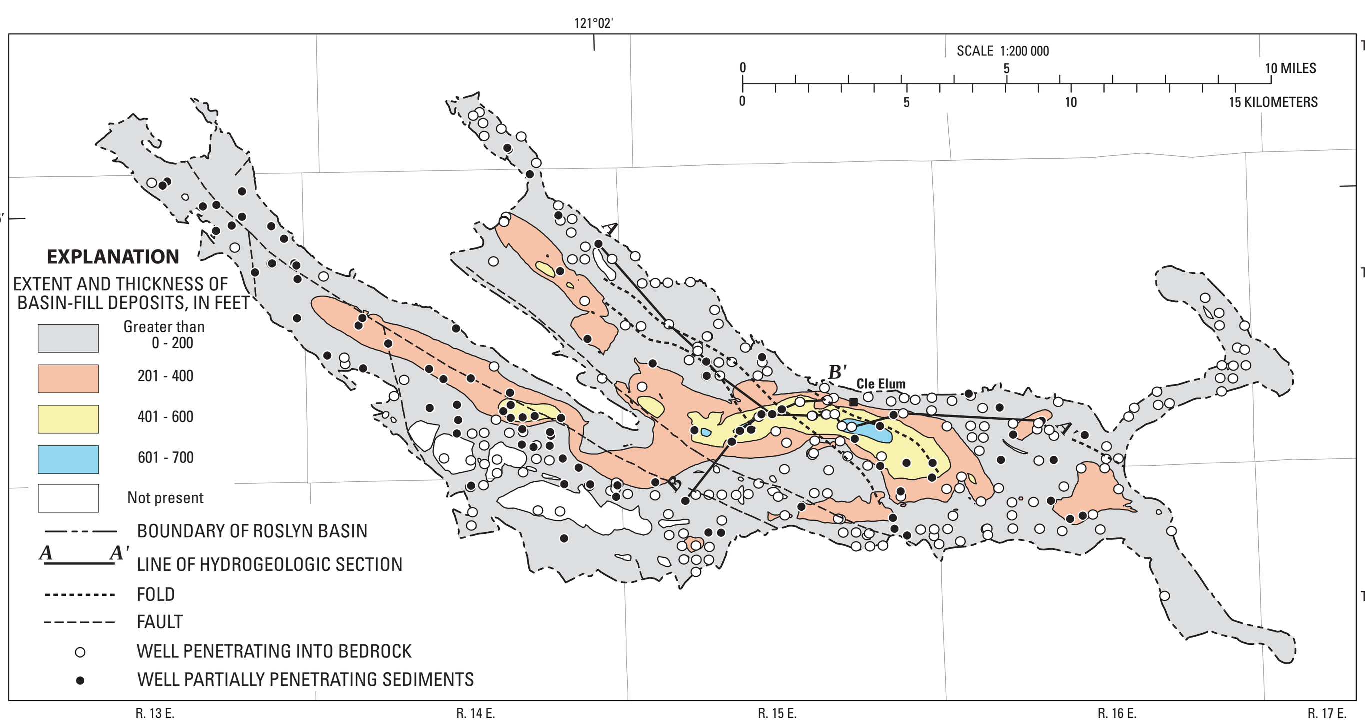
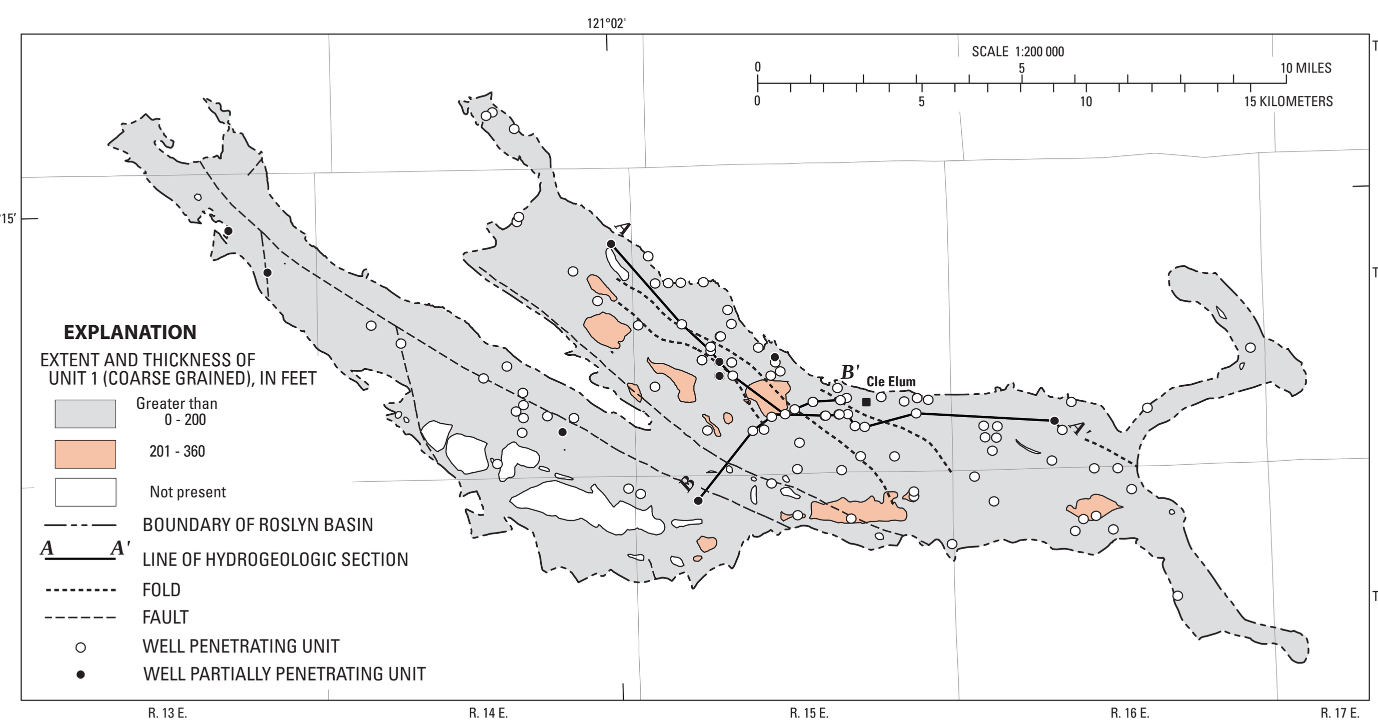
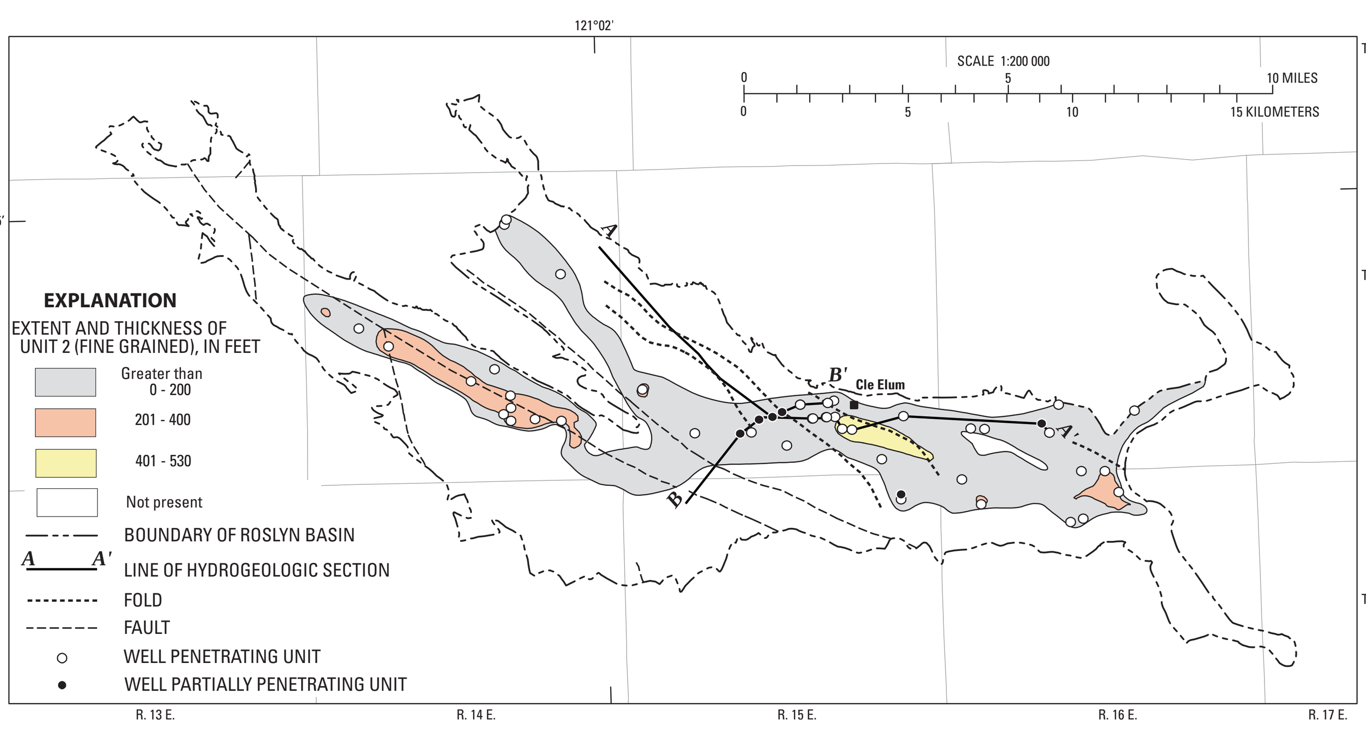
Universal Transverse Mercator projection, Zone 10
Horizontal Datum: North American Datum of 1927 (NAD 27)

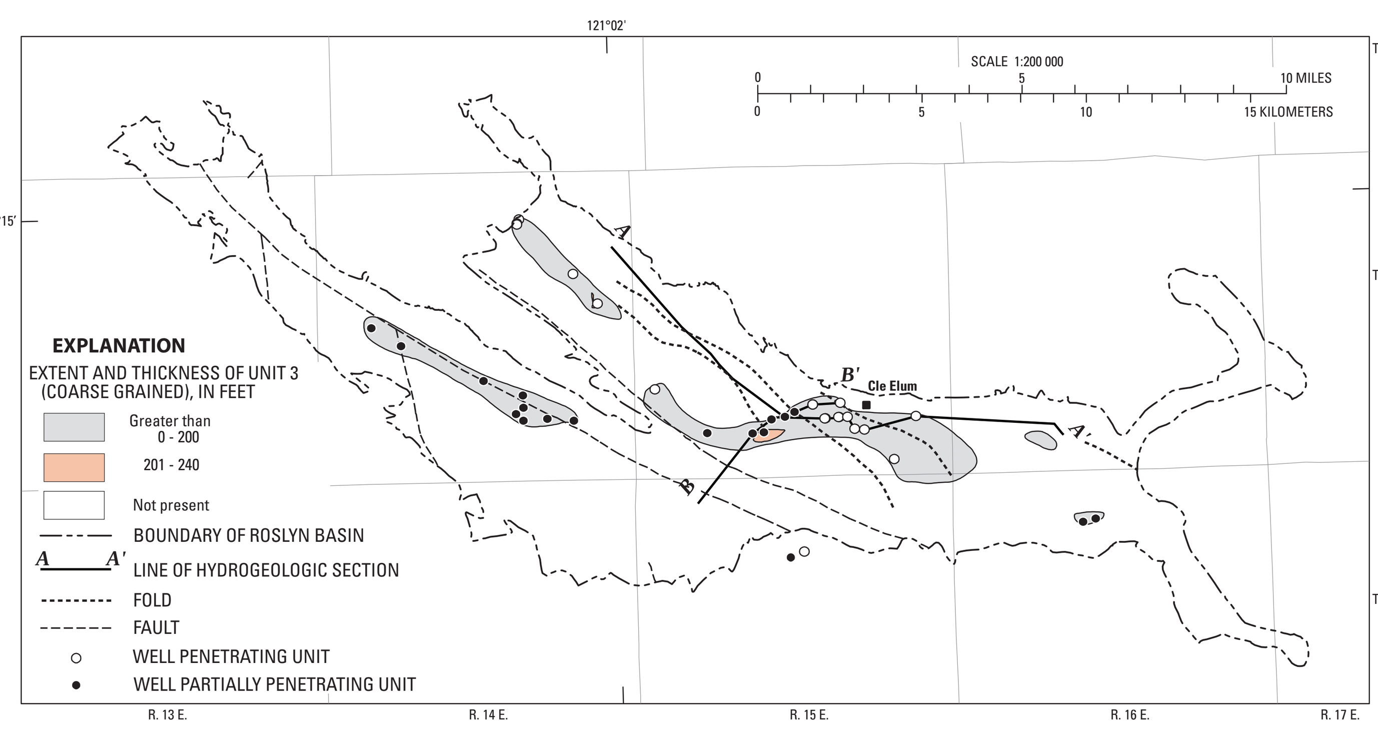






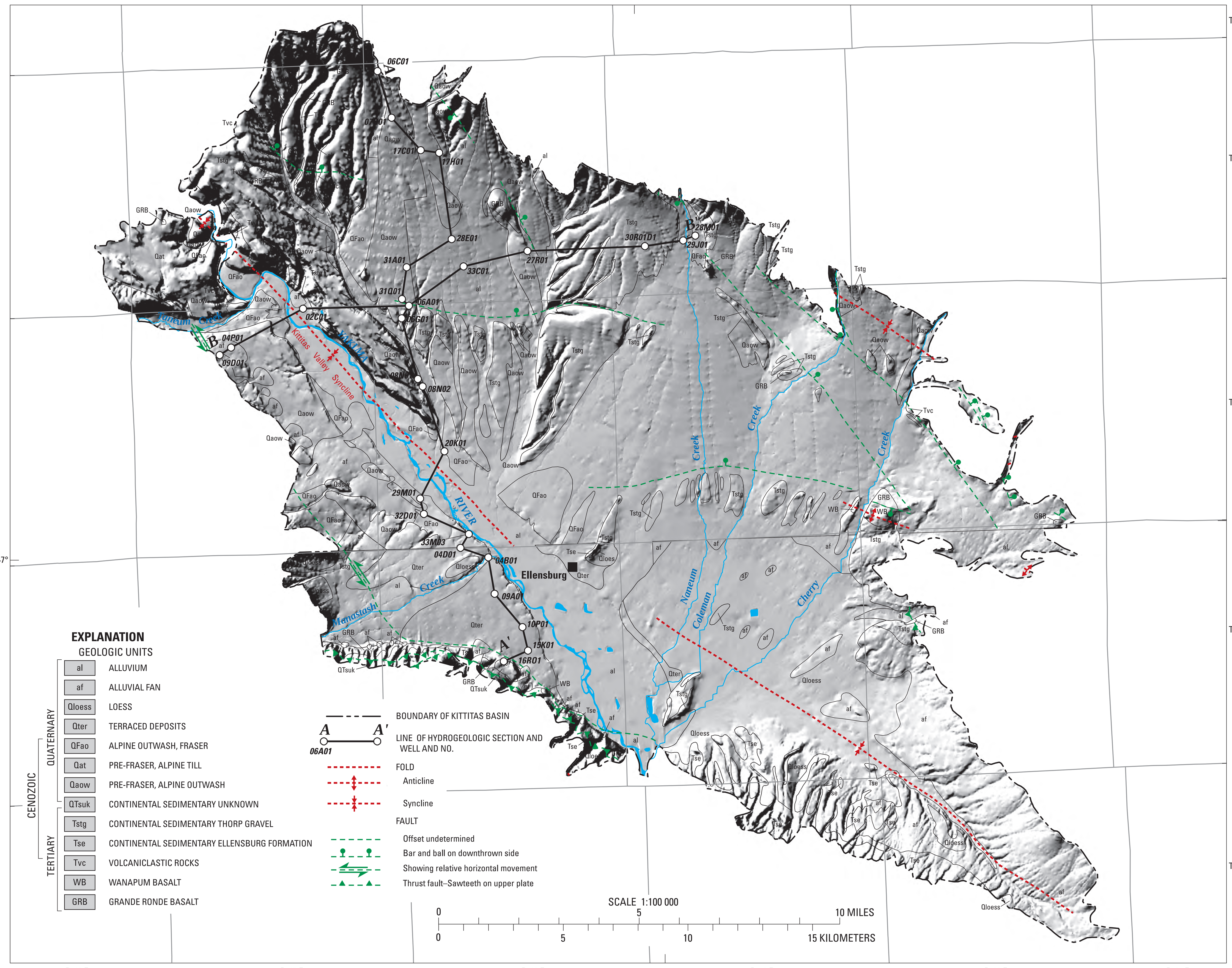

# Maps and Hydrogeologic Sections Showing Surficial Geology, Extent and Thickness of Basin-fill Deposits, Hydrogeologic Units, and Locations of Selected Wells in the Roslyn Basin, Yakima River Basin, Washington

By
Myrtle A. Jones, John Vaccaro, and Anni M. Watkins
2006

Prepared in cooperation with the
BUREAU OF RECLAMATION, WASHINGTON STATE DEPARTMENT OF ECOLOGY, AND THE YAKAMA NATION

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY



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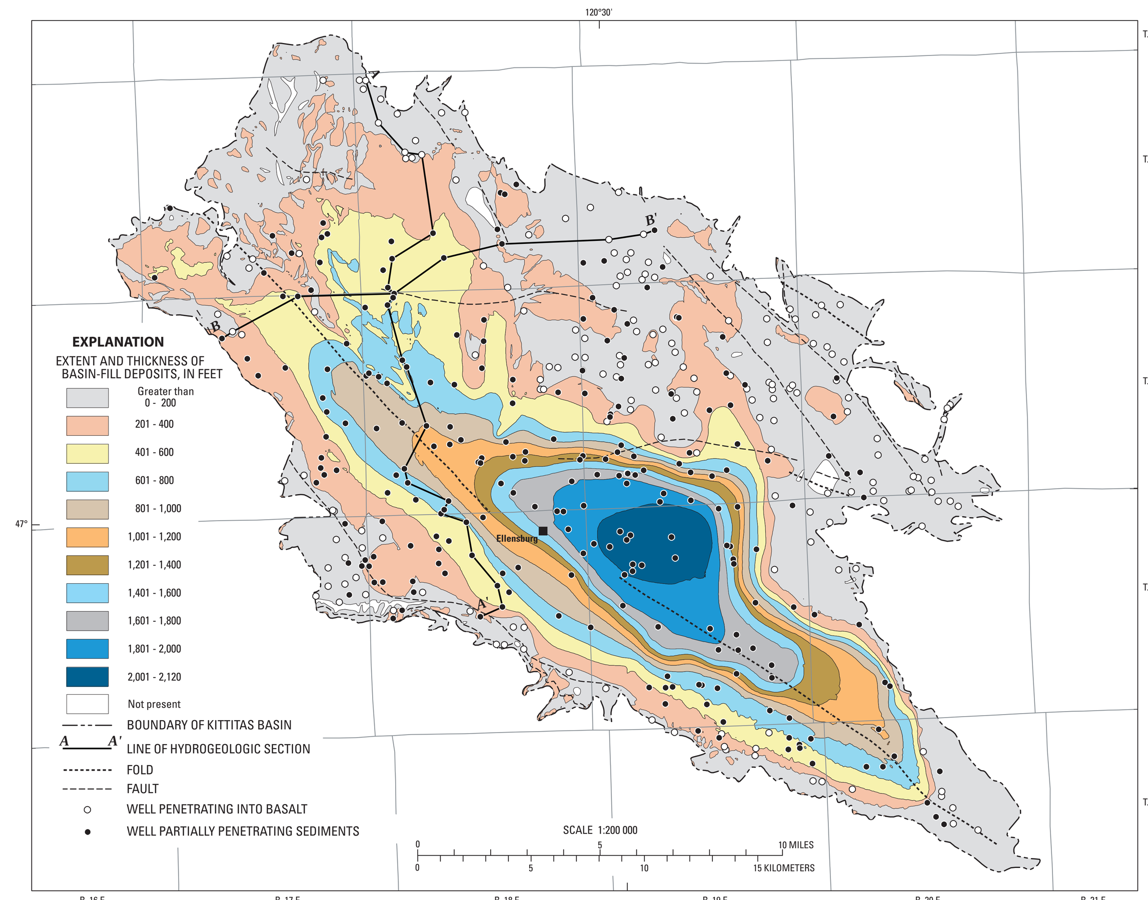
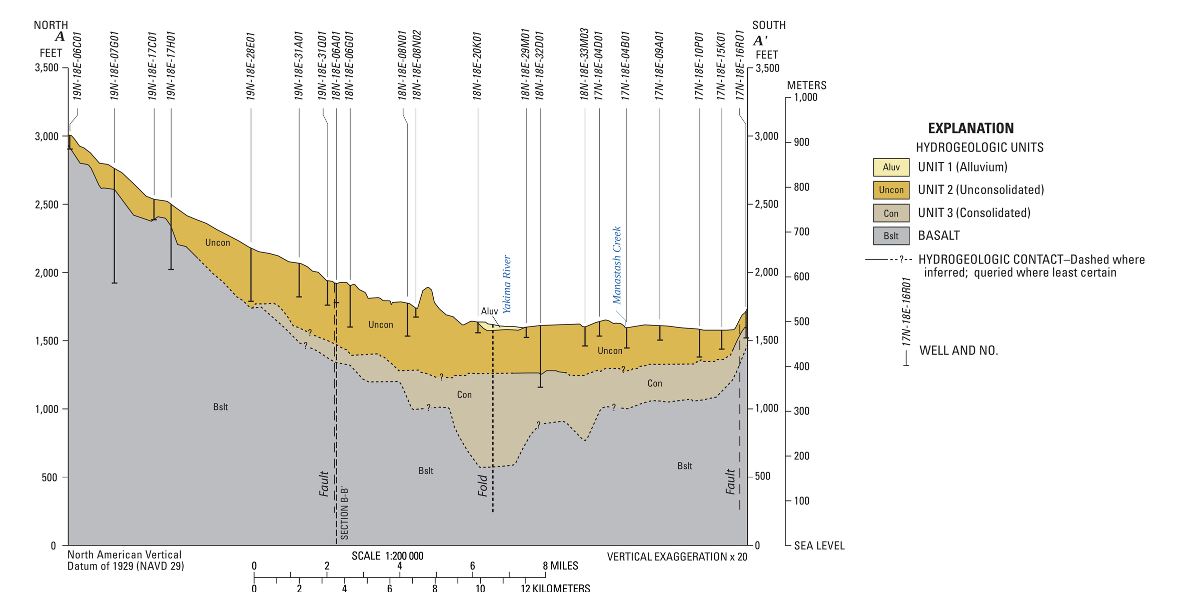
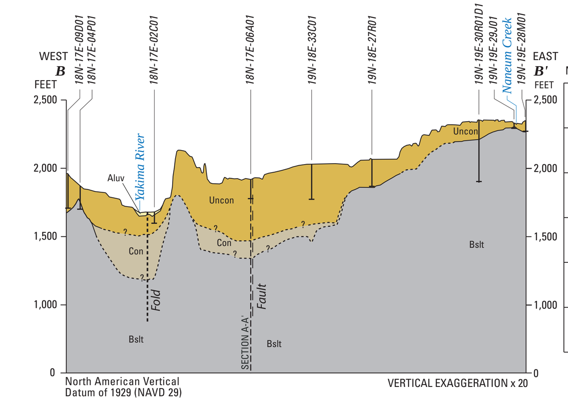
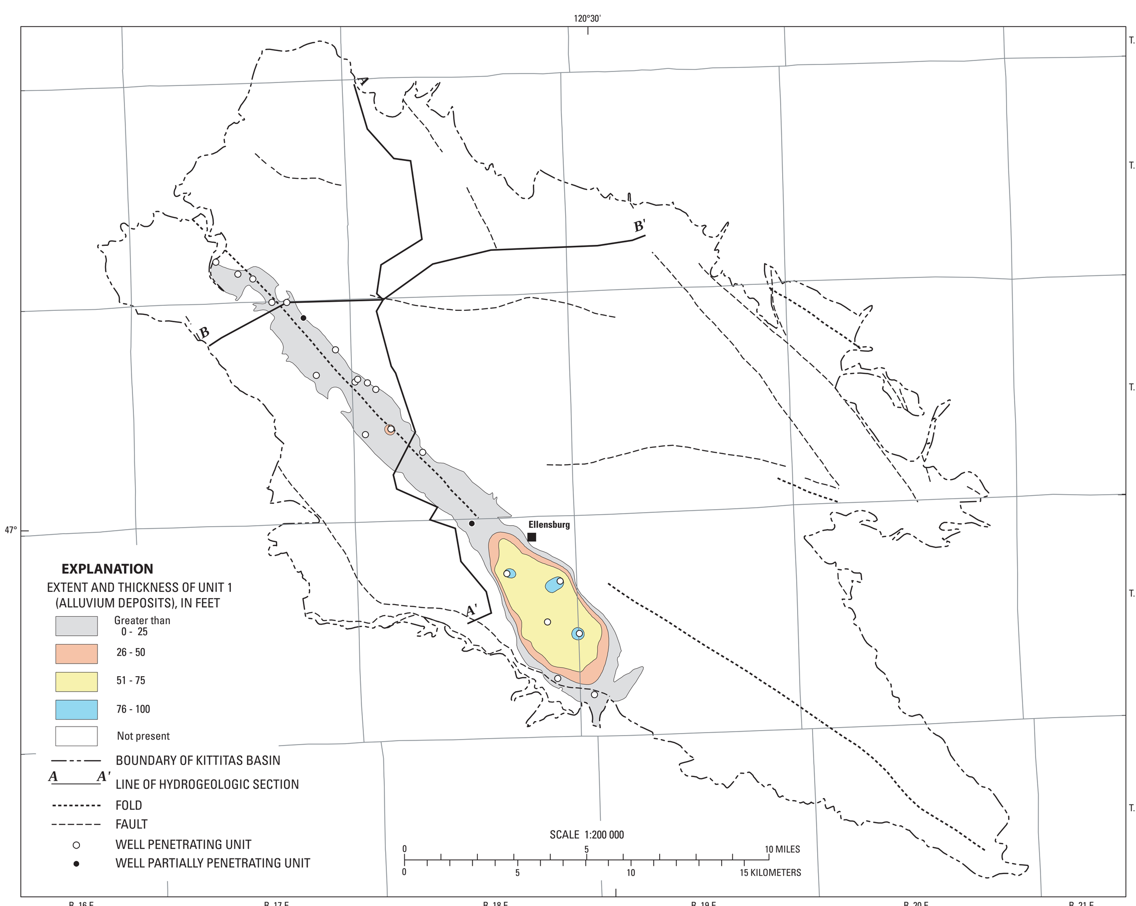
Washington Division of Geology and Earth Resources
digital data, 1983, 1:100,000
Universal Transverse Mercator projection, Zone 10
Horizontal Datum: North American Datum of 1927 (NAD 27)

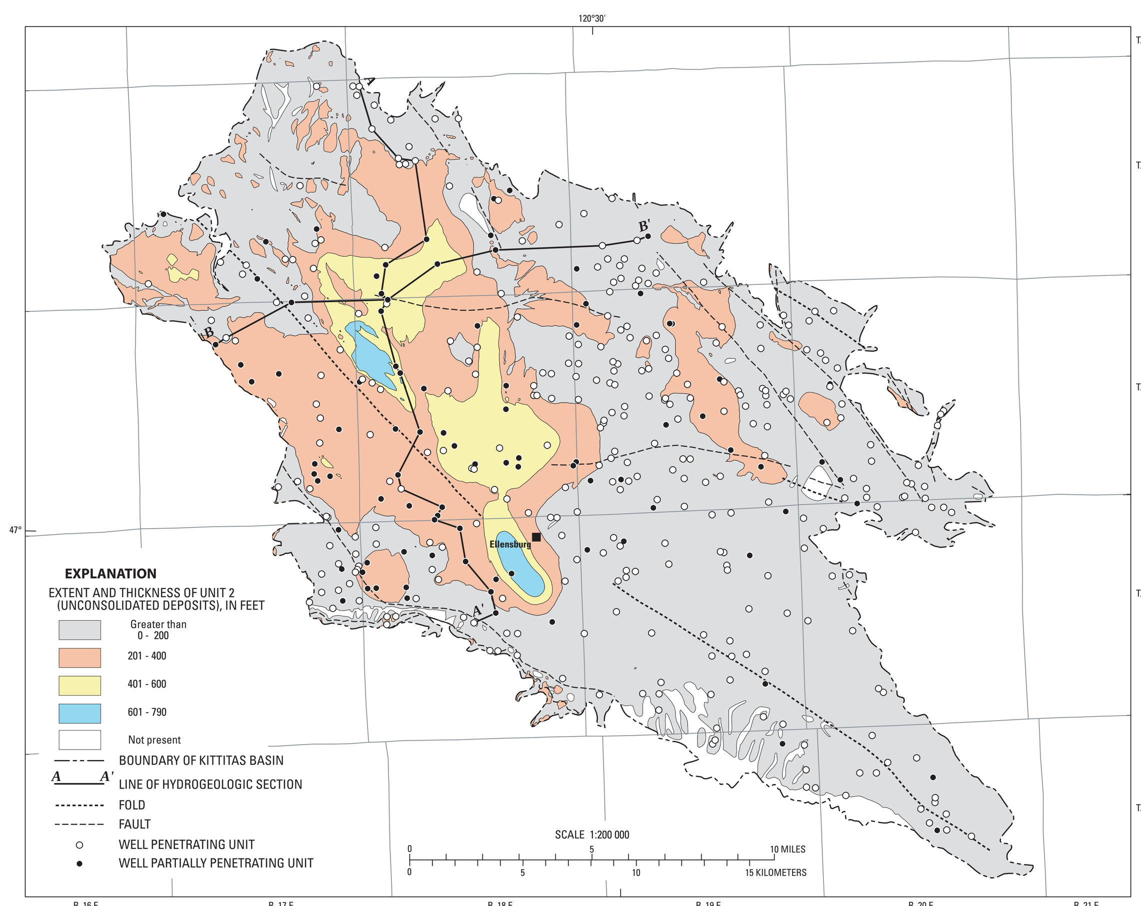


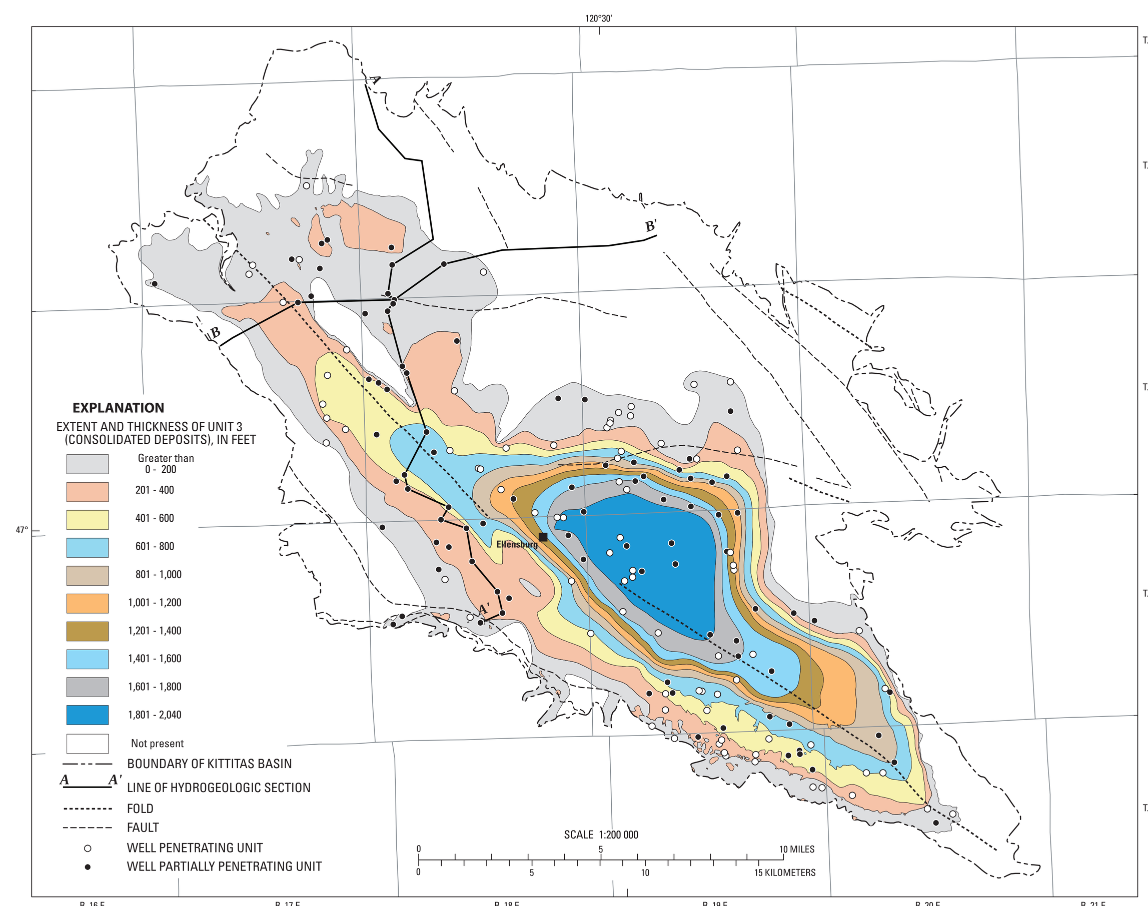








# Maps and Hydrogeologic Sections Showing Surficial Geology, Extent and Thickness of Basin-fill Deposits, Hydrogeologic Units, and Locations of Selected Wells in the Kittitas Basin, Yakima River Basin, Washington

By
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2006

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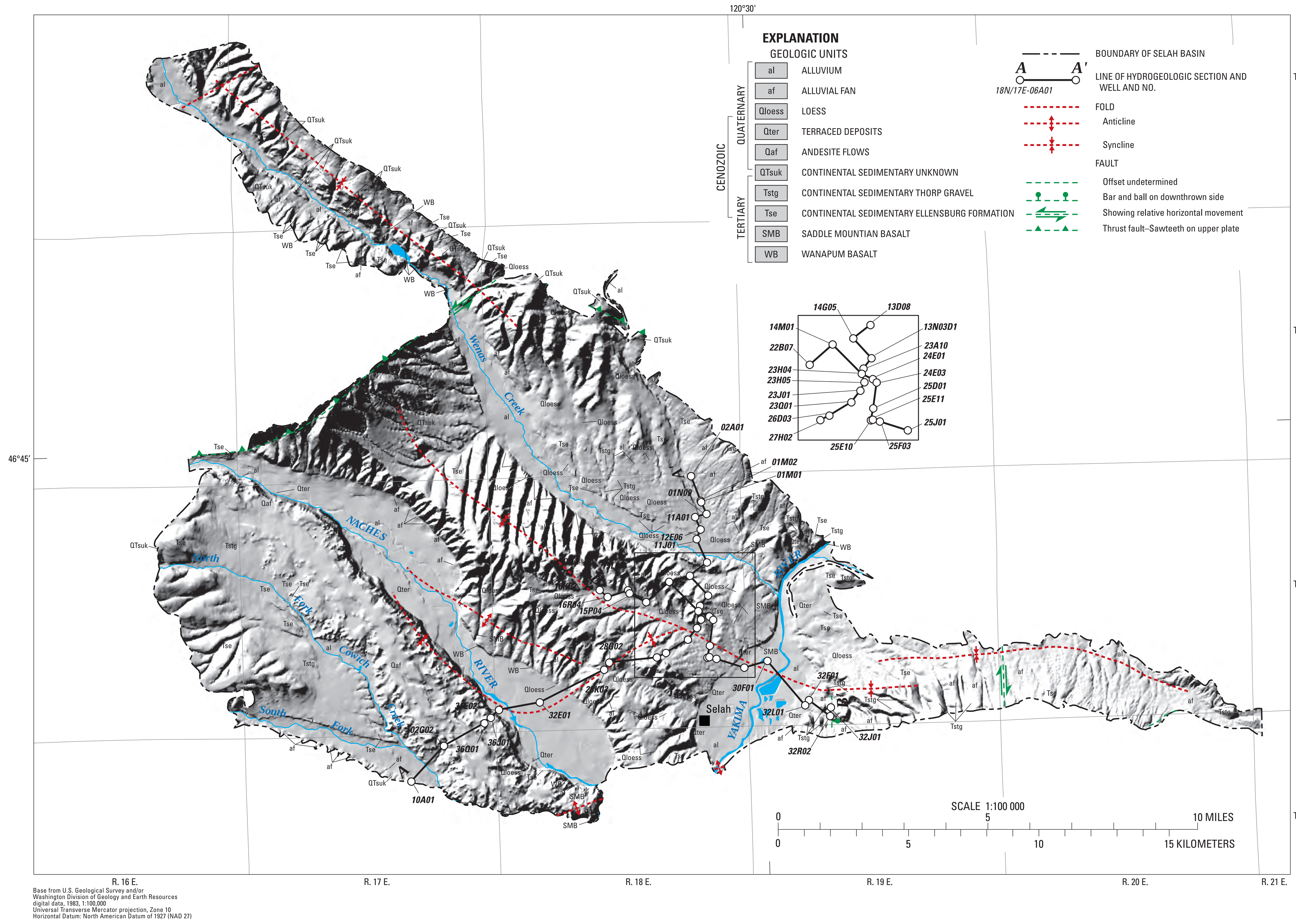
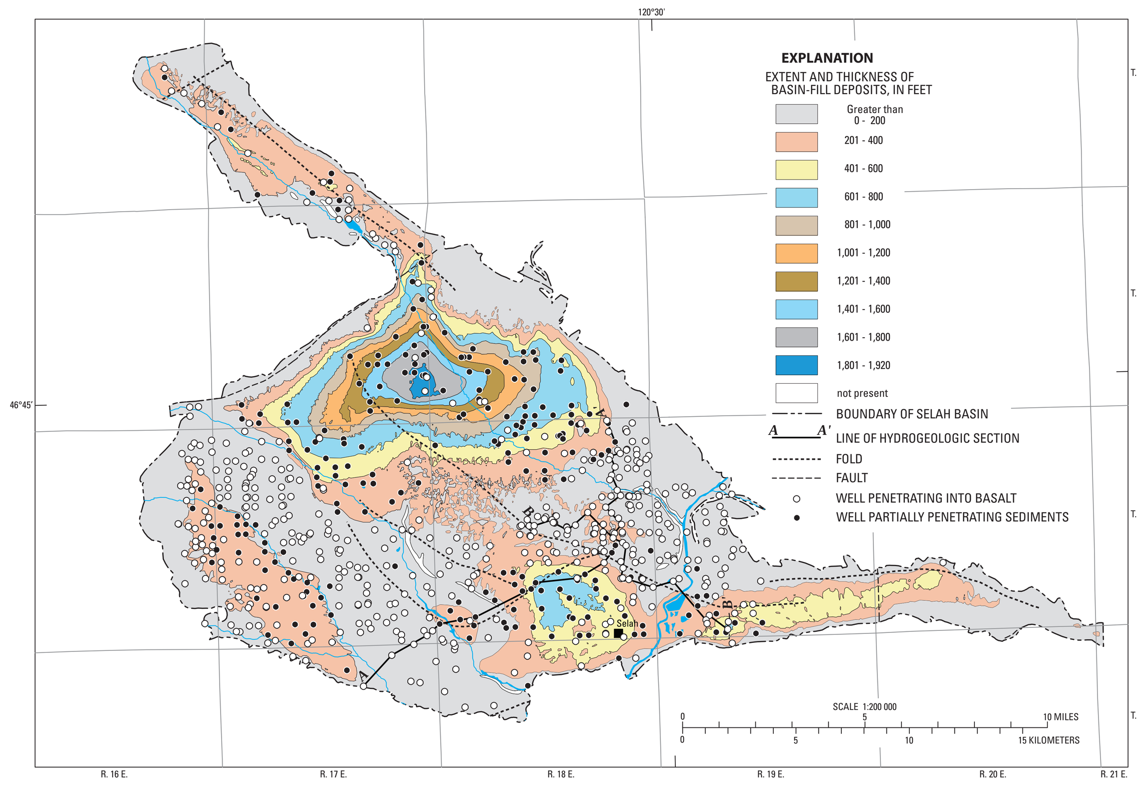
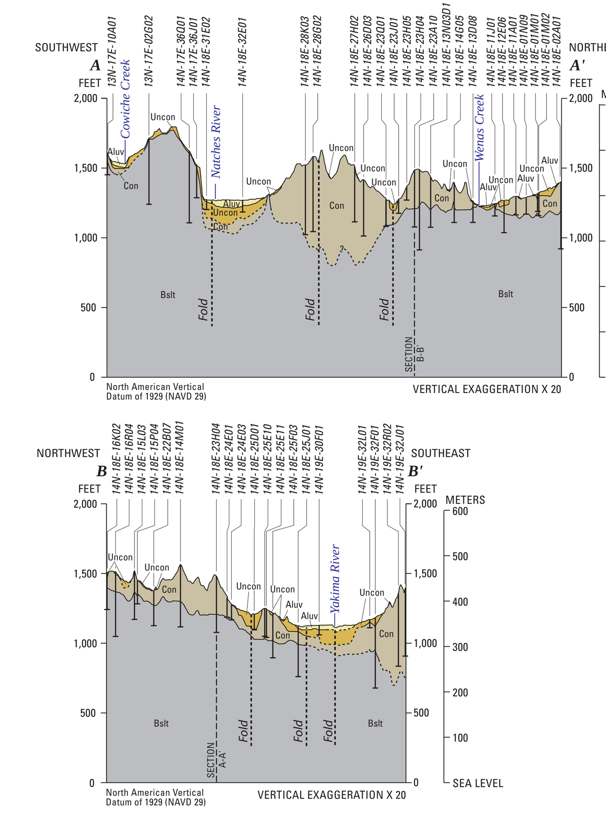
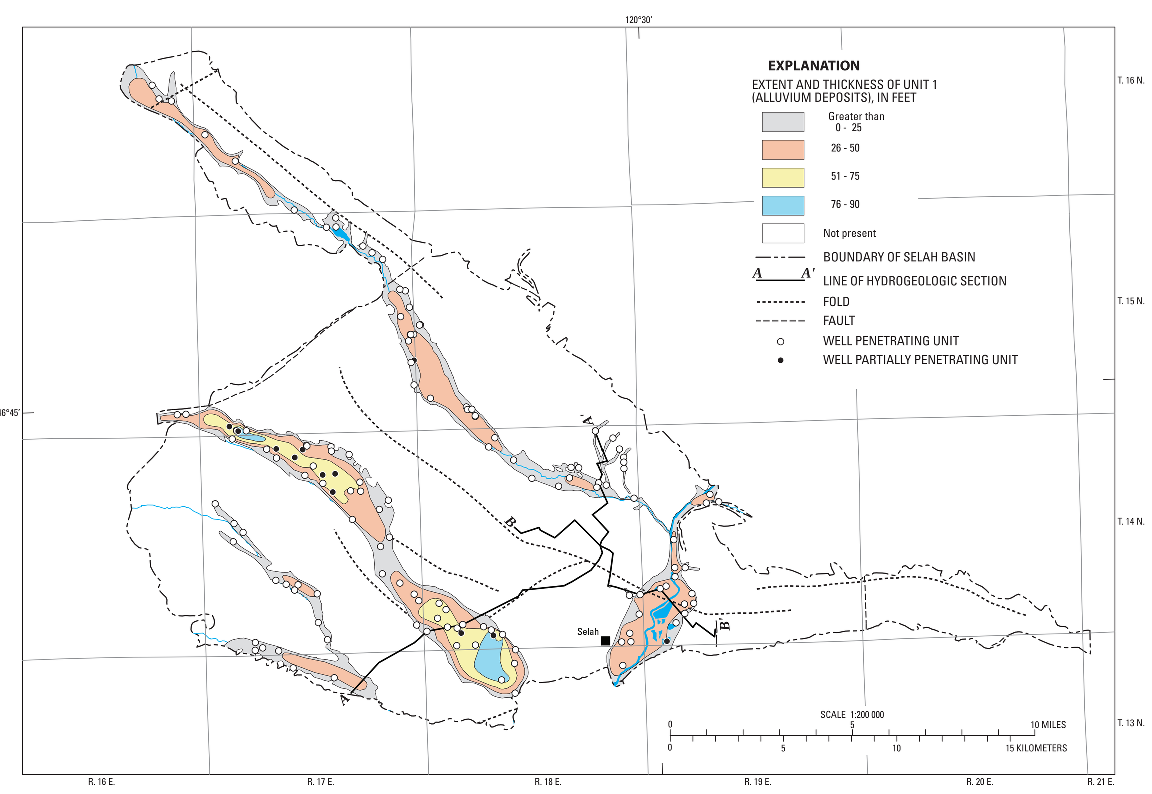
BUREAU OF RECLAMATION, WASHINGTON STATE DEPARTMENT OF ECOLOGY, AND THE YAKAMA NATION

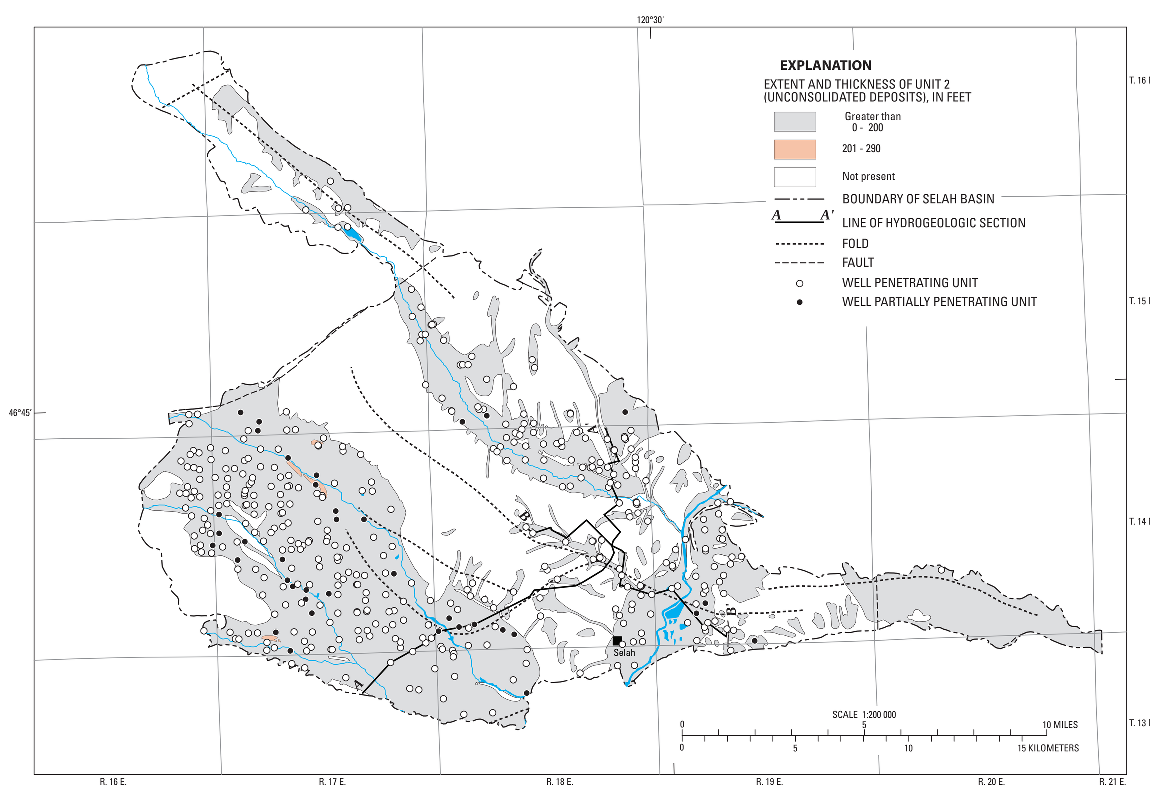


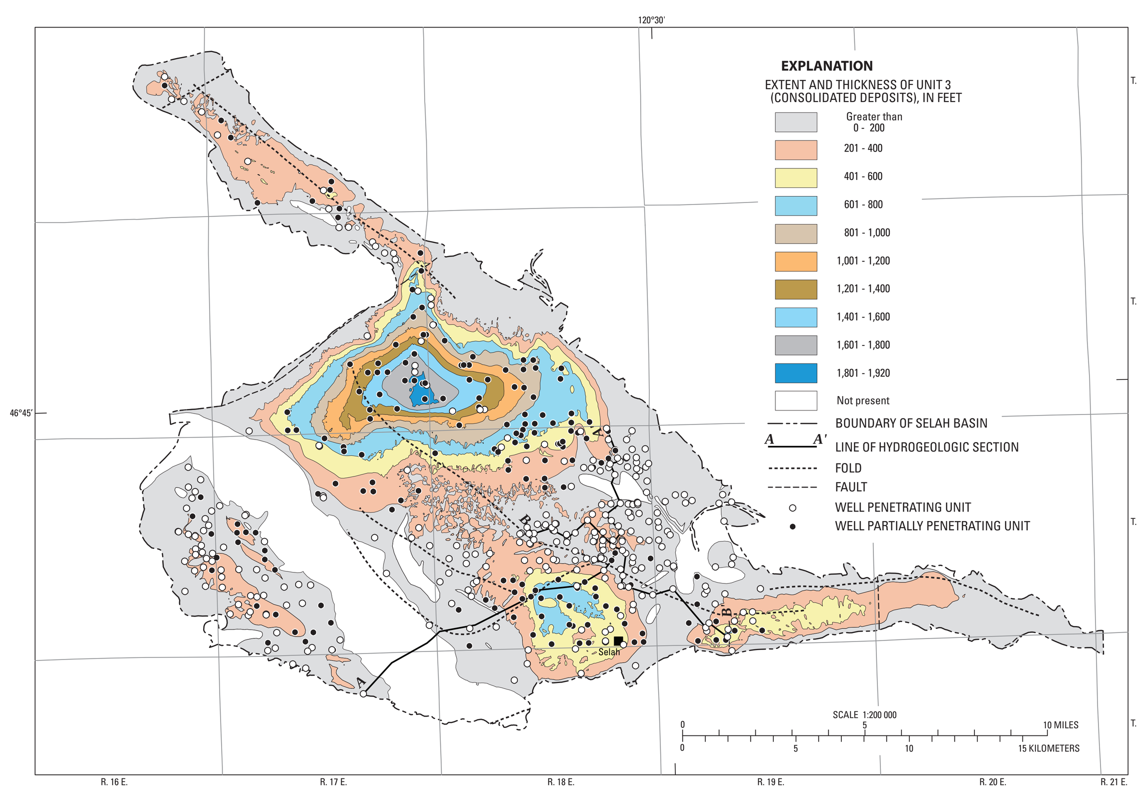








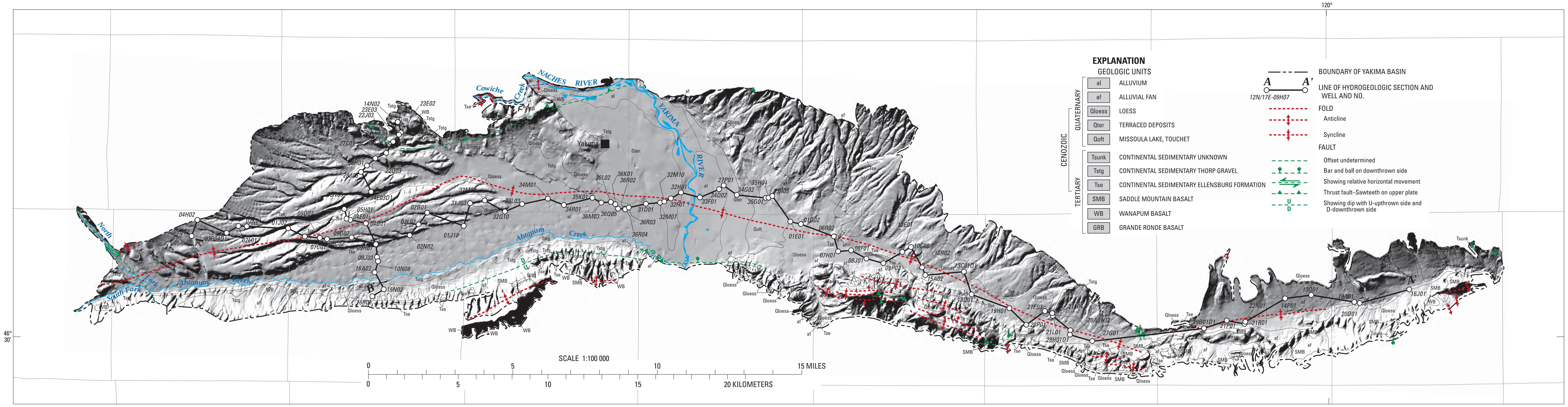


# Maps and Hydrogeologic Sections Showing Surficial Geology, Extent and Thickness of Basin-fill Deposits, Hydrogeologic Units, and Locations of Selected Wells in the Selah Basin, Yakima River Basin, Washington

By
Myrtle A. Jones, John Vaccaro, and Anni M. Watkins
2006

Prepared in cooperation with the
BUREAU OF RECLAMATION, WASHINGTON STATE DEPARTMENT OF ECOLOGY, AND THE YAKAMA NATION



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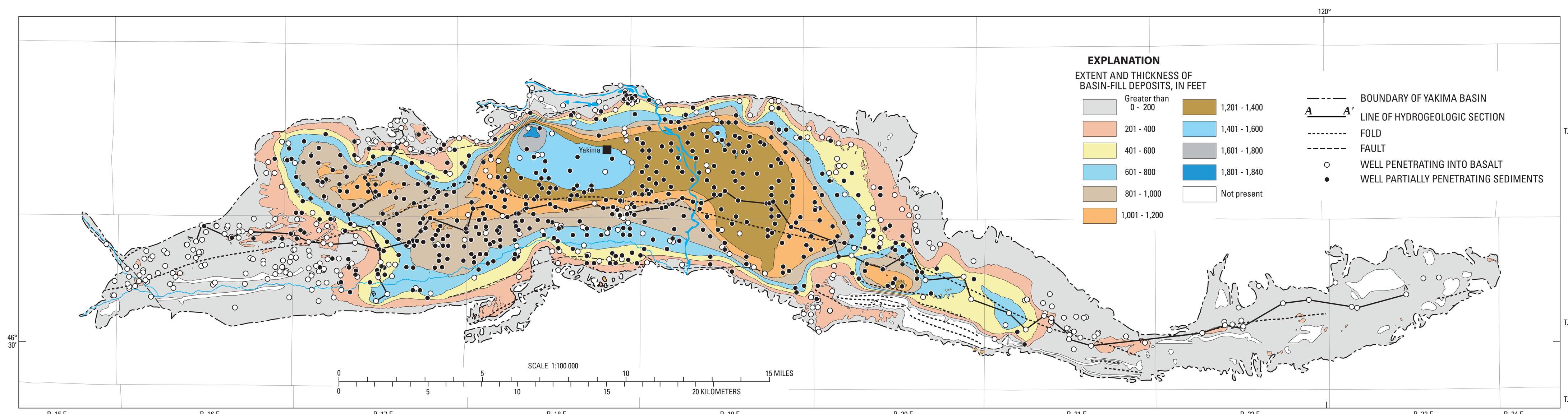
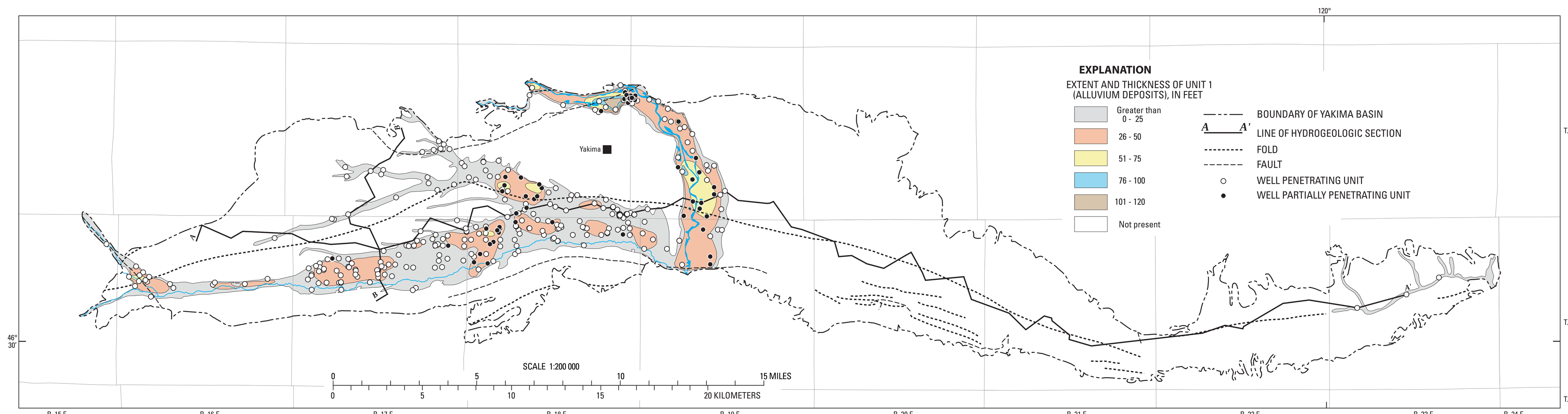
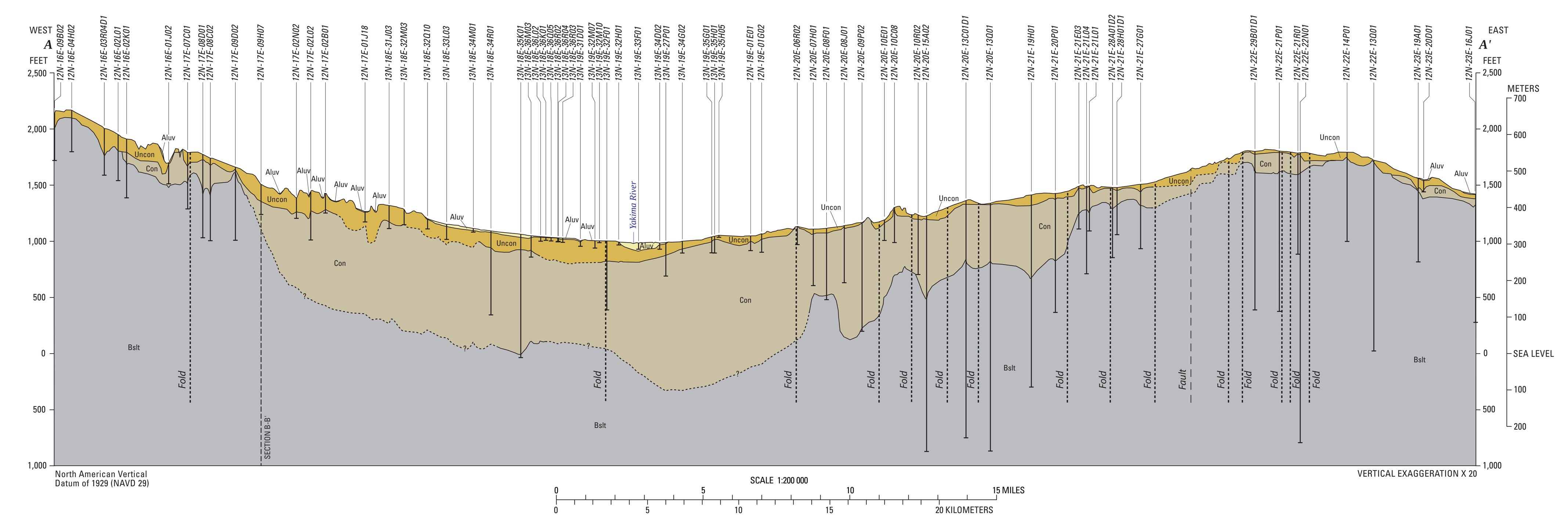
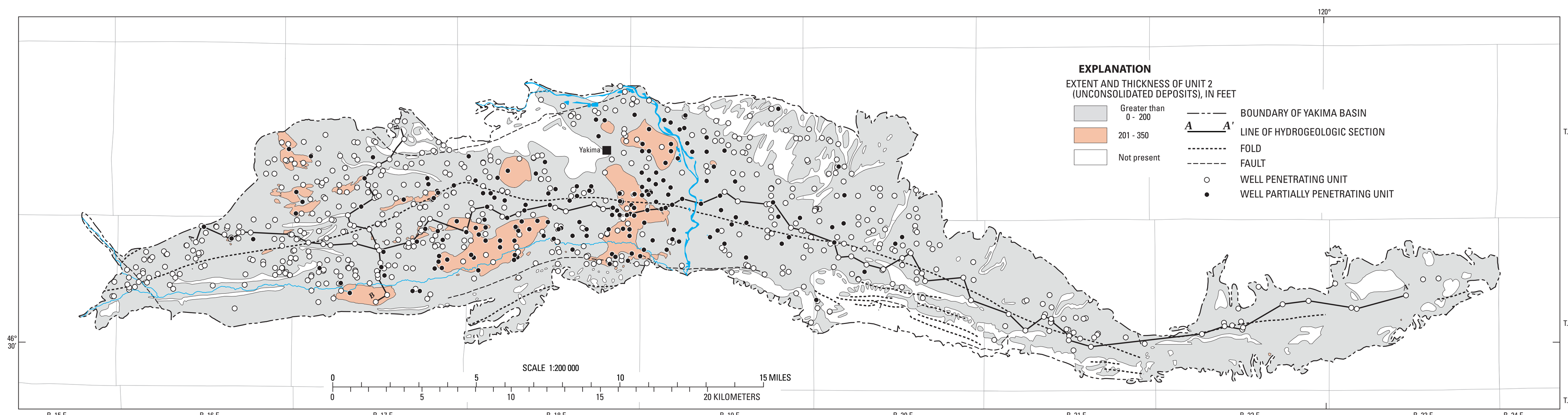
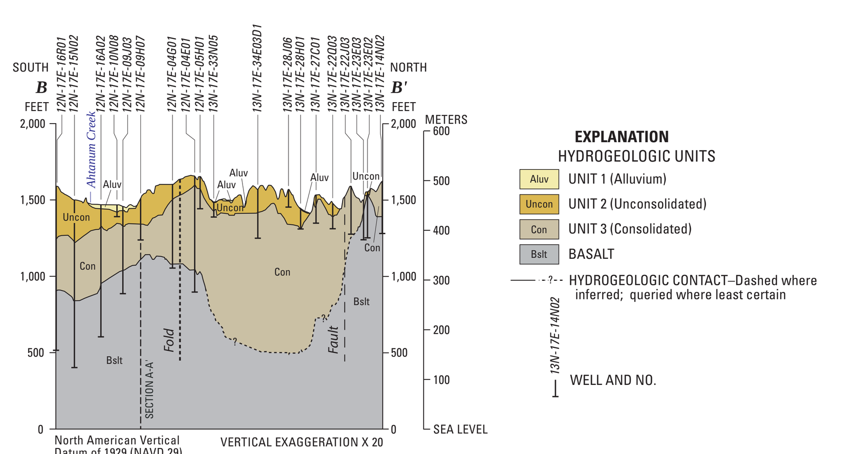
Horizontal Datum: North American Datum of 1927 (NAD 27)

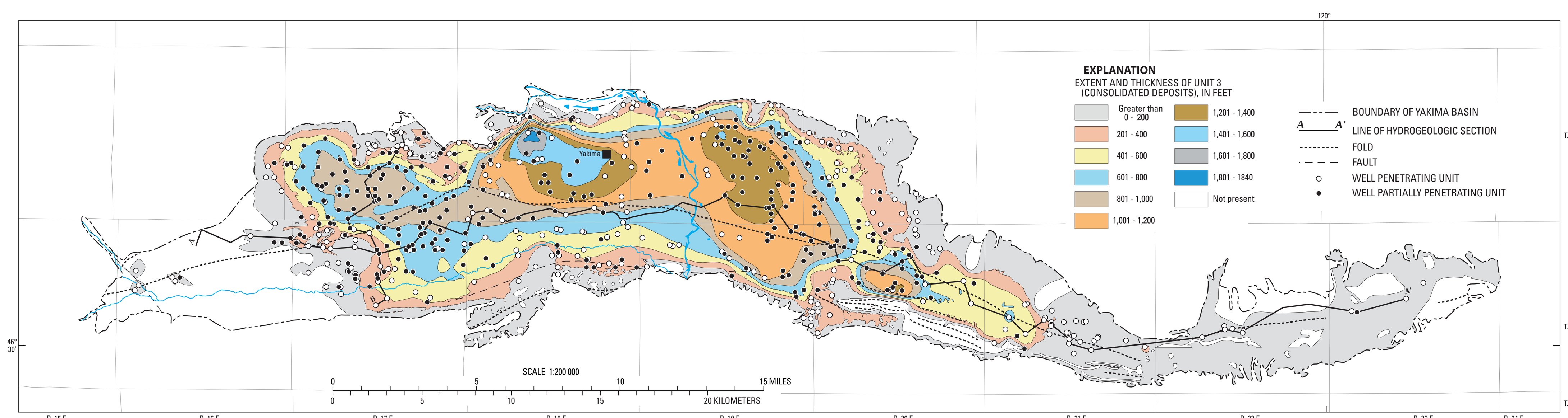








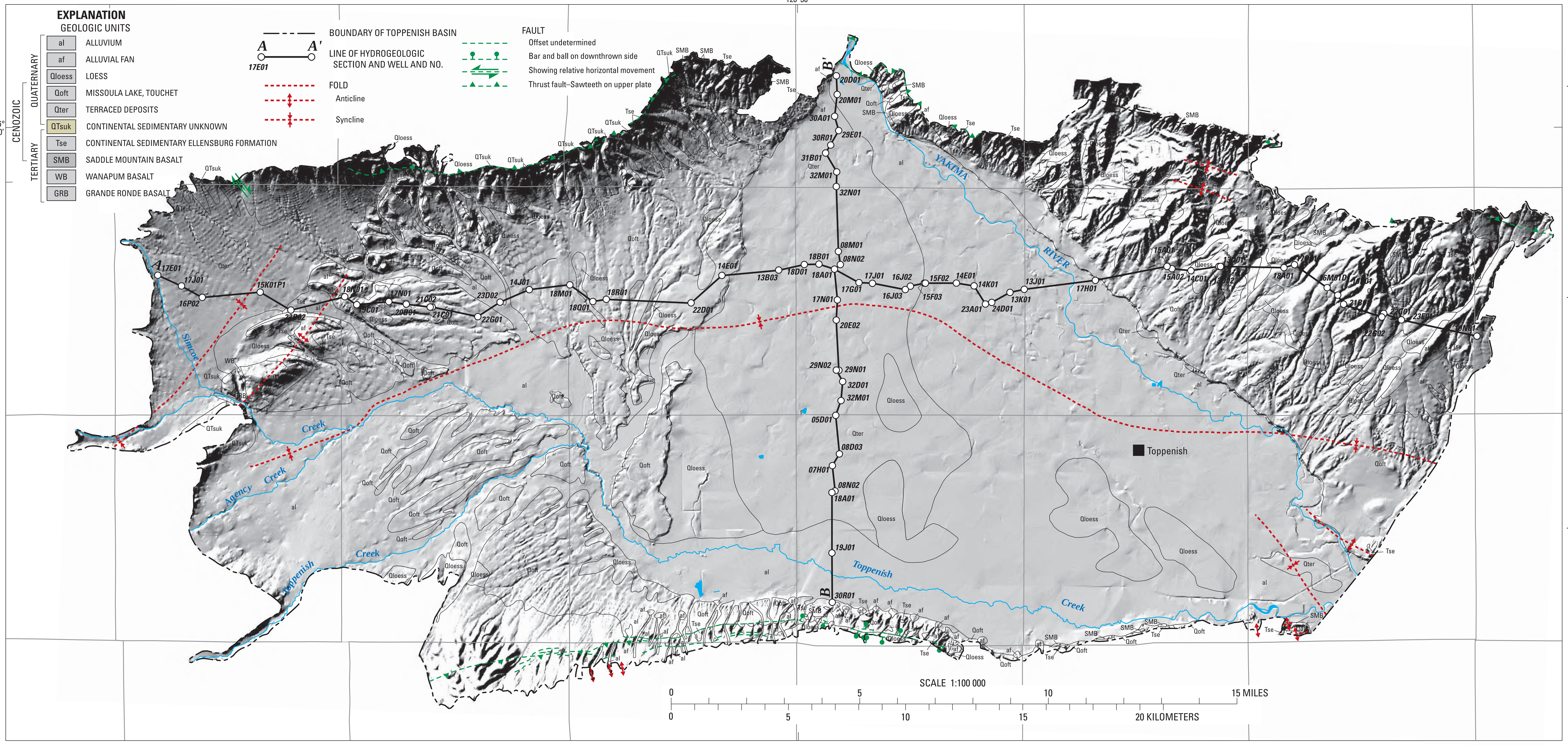


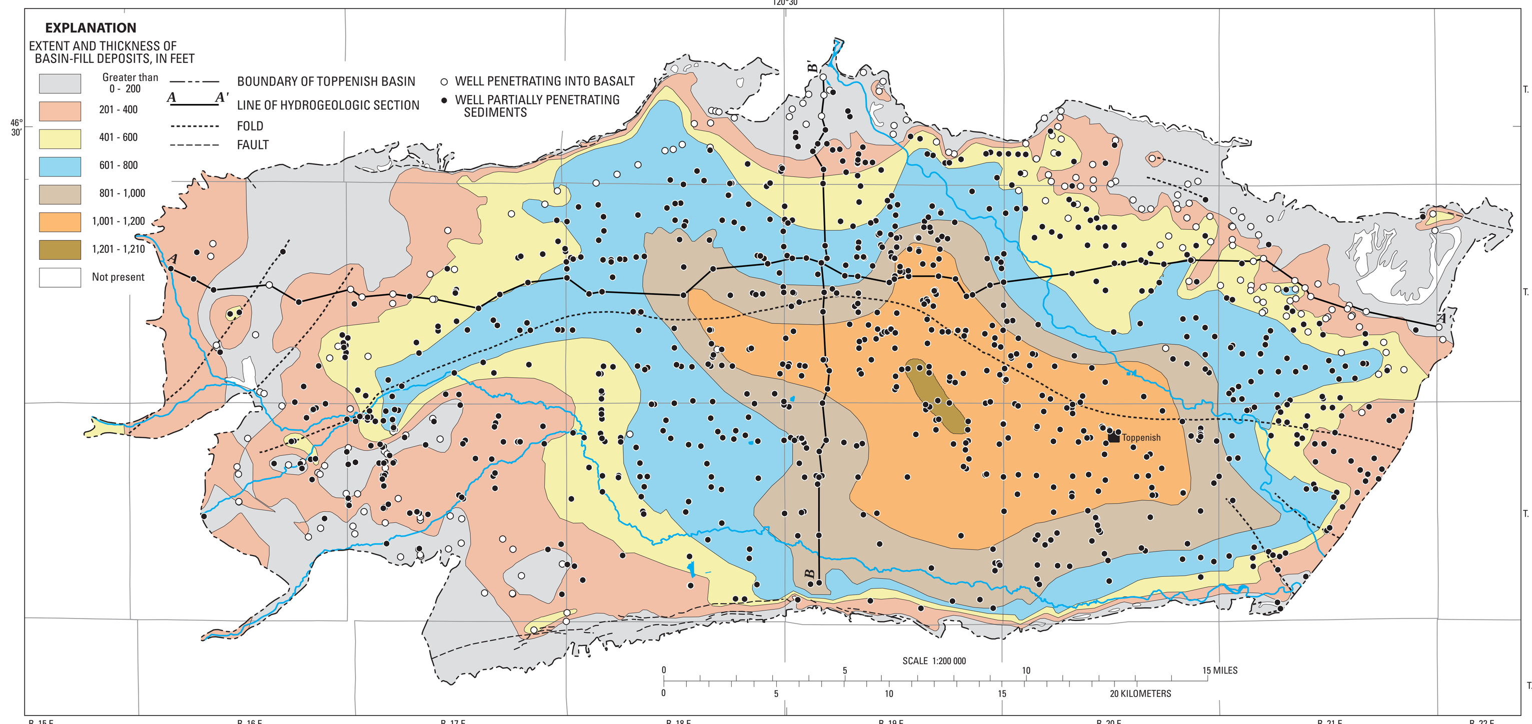


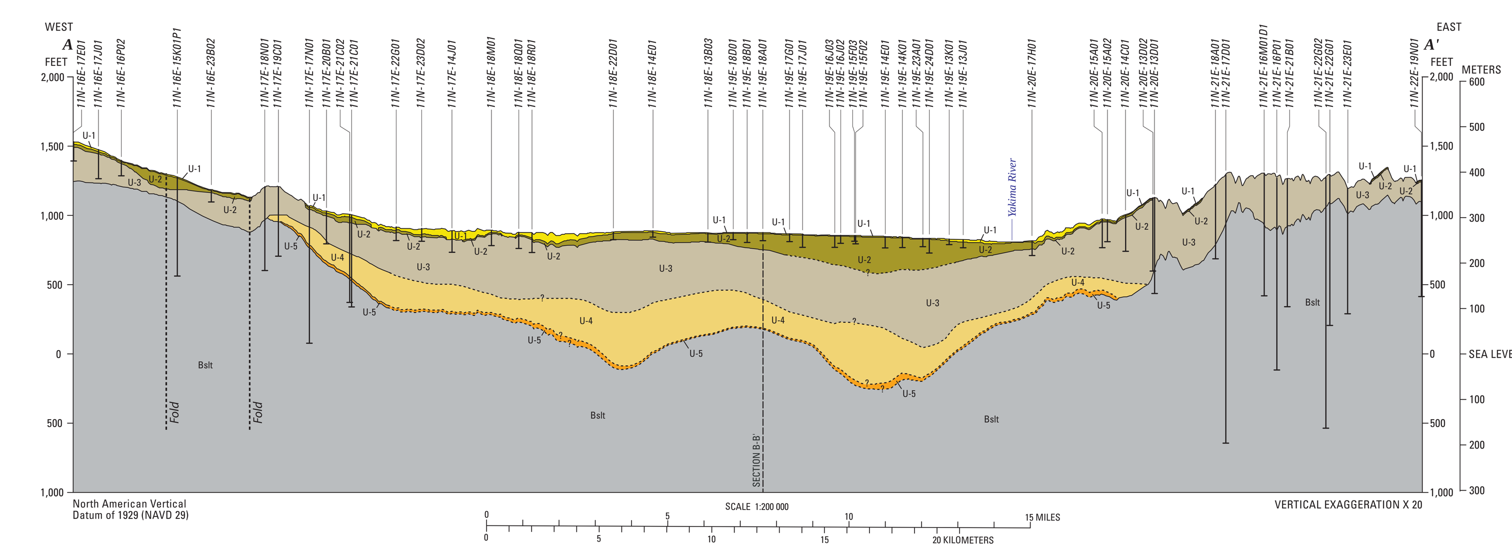
# Maps and Hydrogeologic Sections Showing Surficial Geology, Extent and Thickness of Basin-fill Deposits, Hydrogeologic Units, and Locations of Selected Wells in the Yakima Basin, Yakima River Basin, Washington

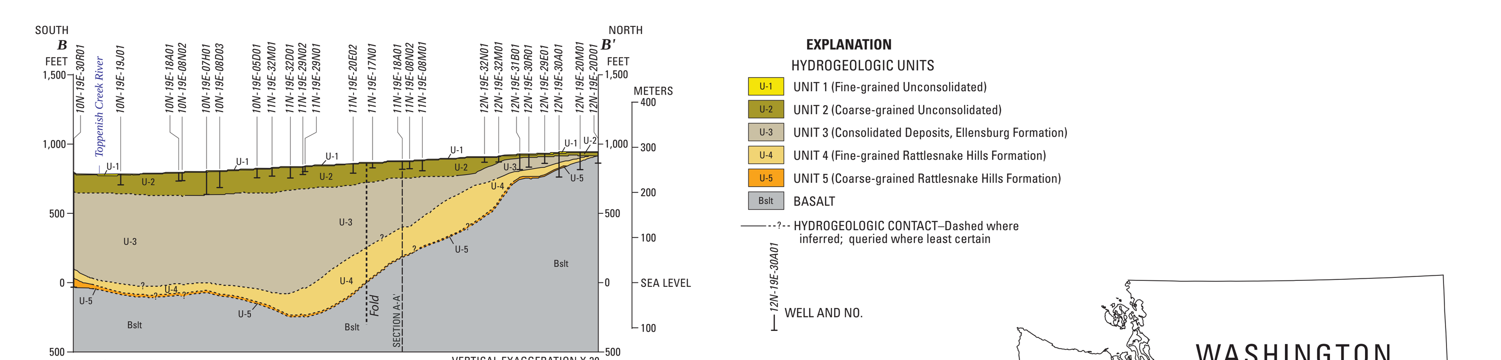
By
Myrtle A. Jones, John Vaccaro, and Anni M. Watkins

2006

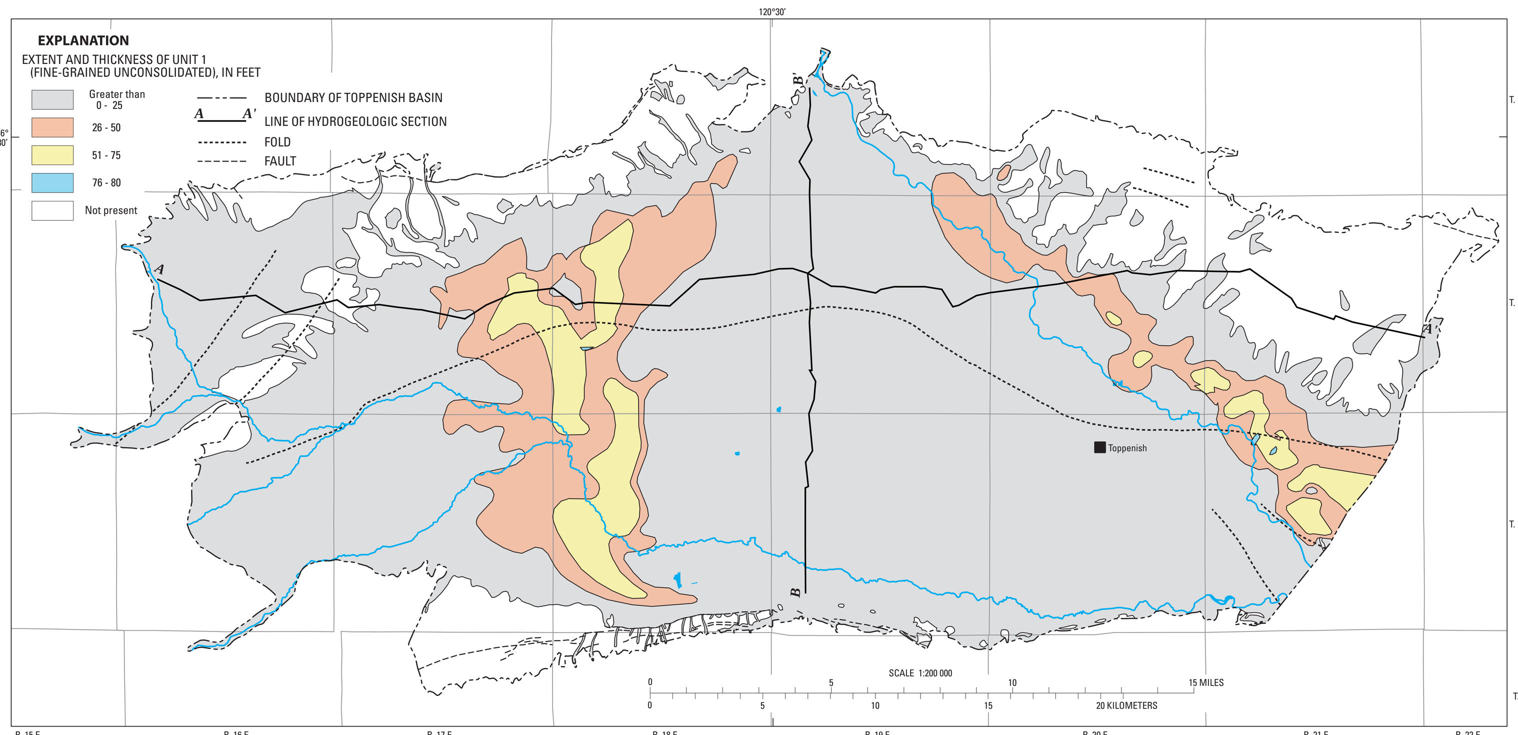


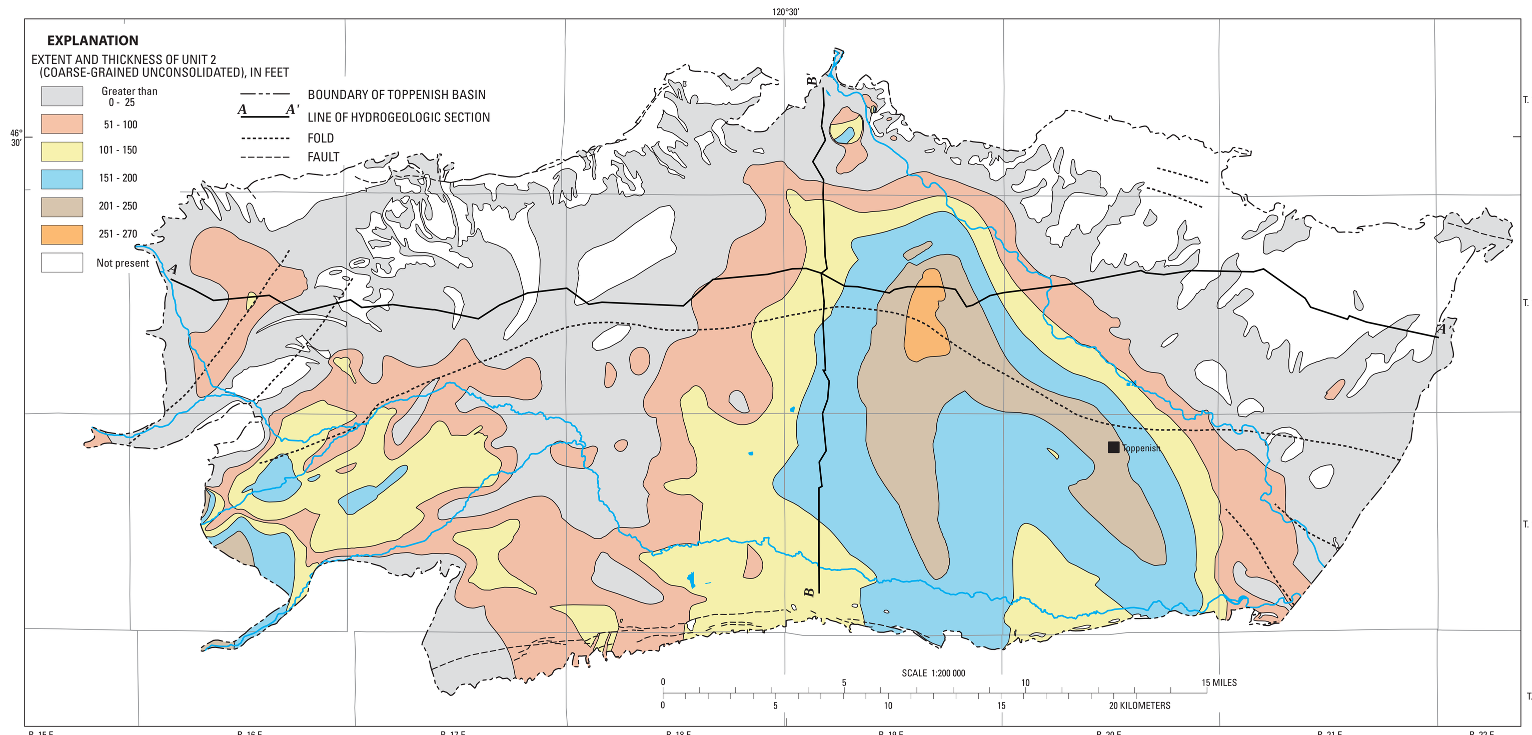



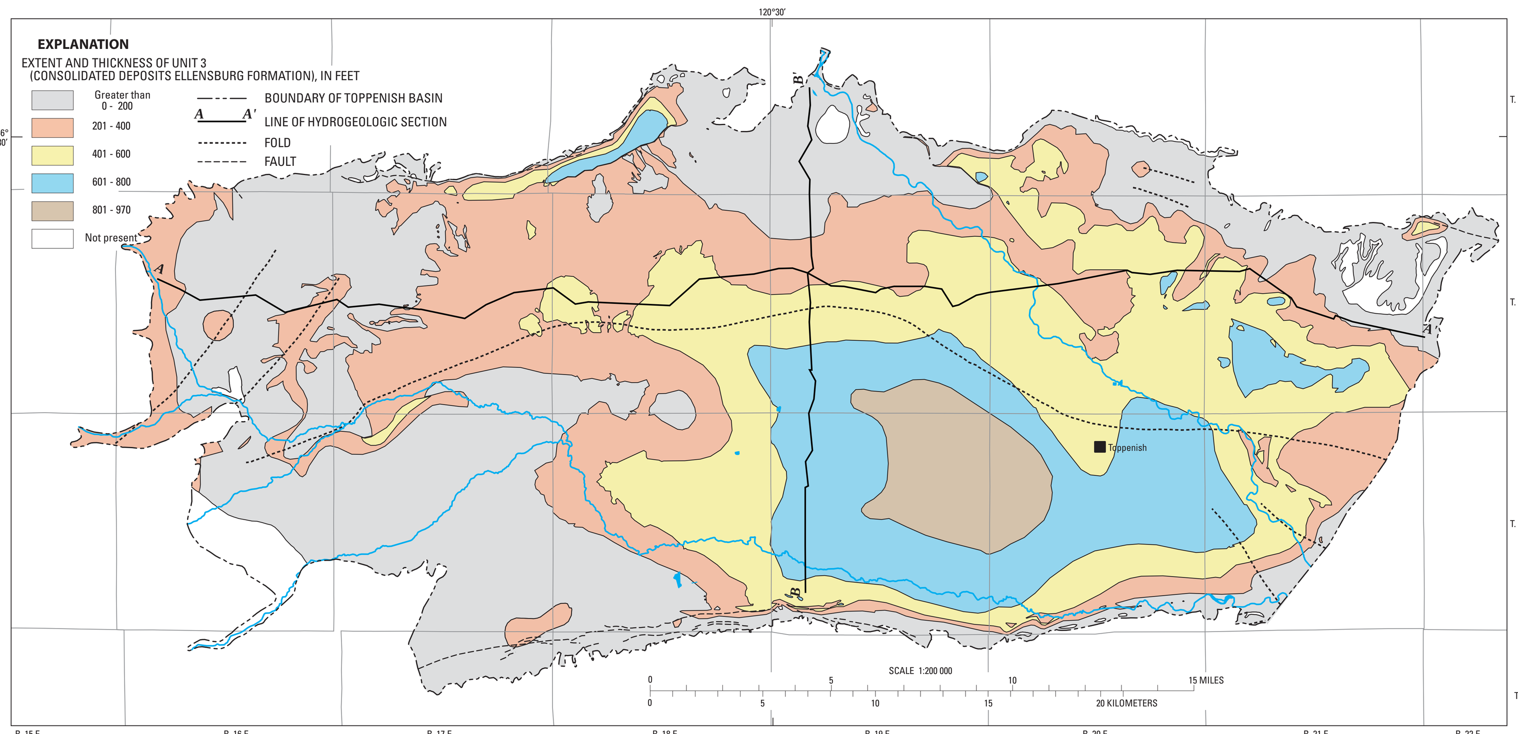



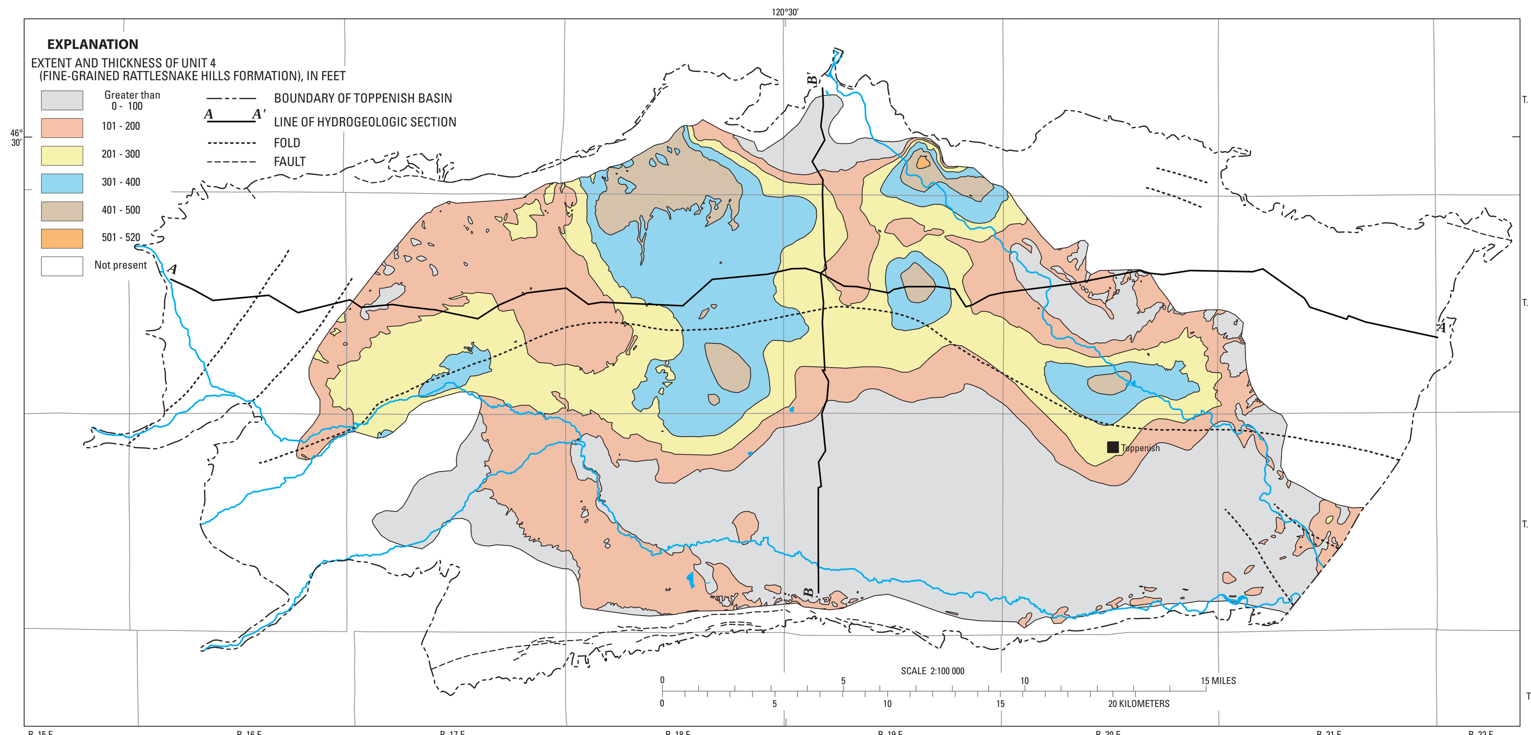



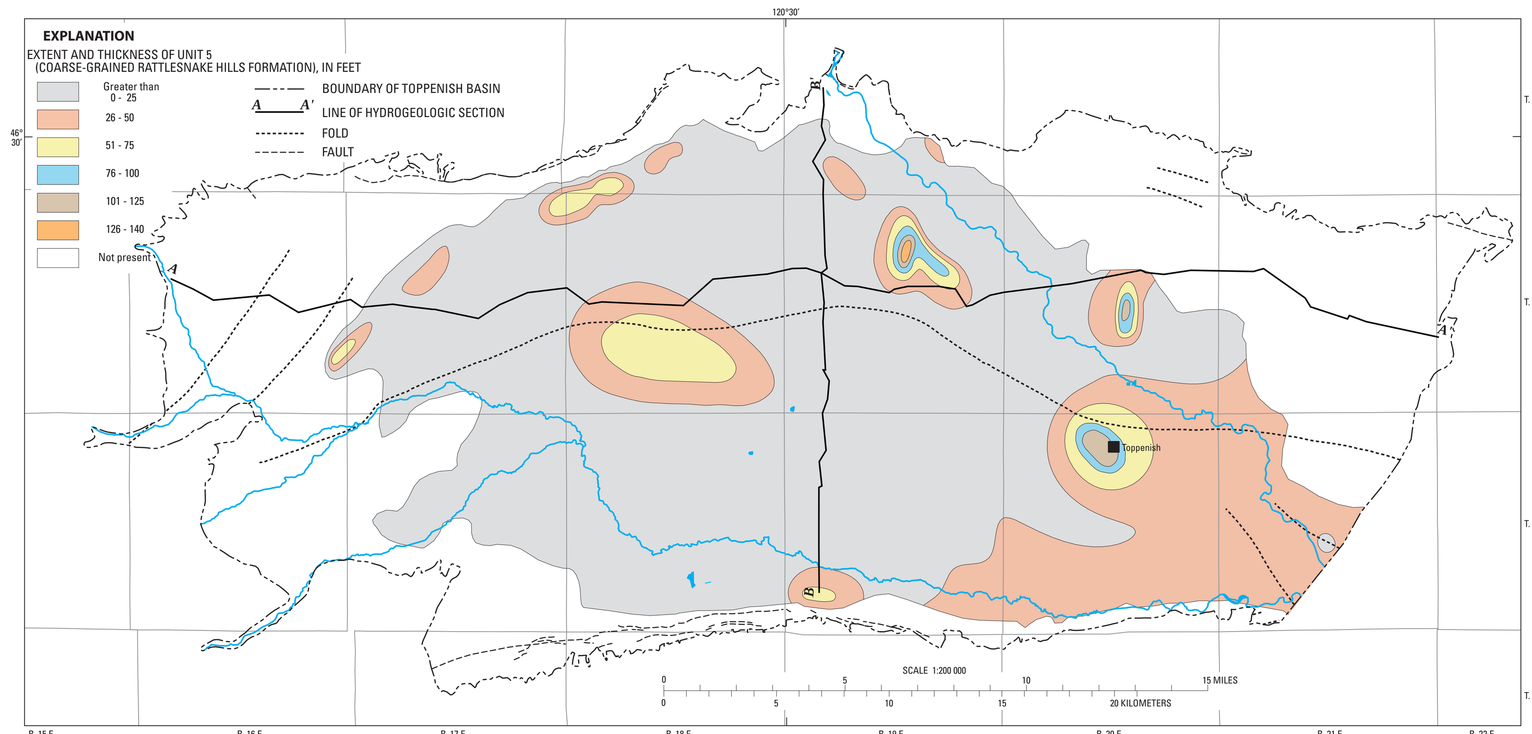




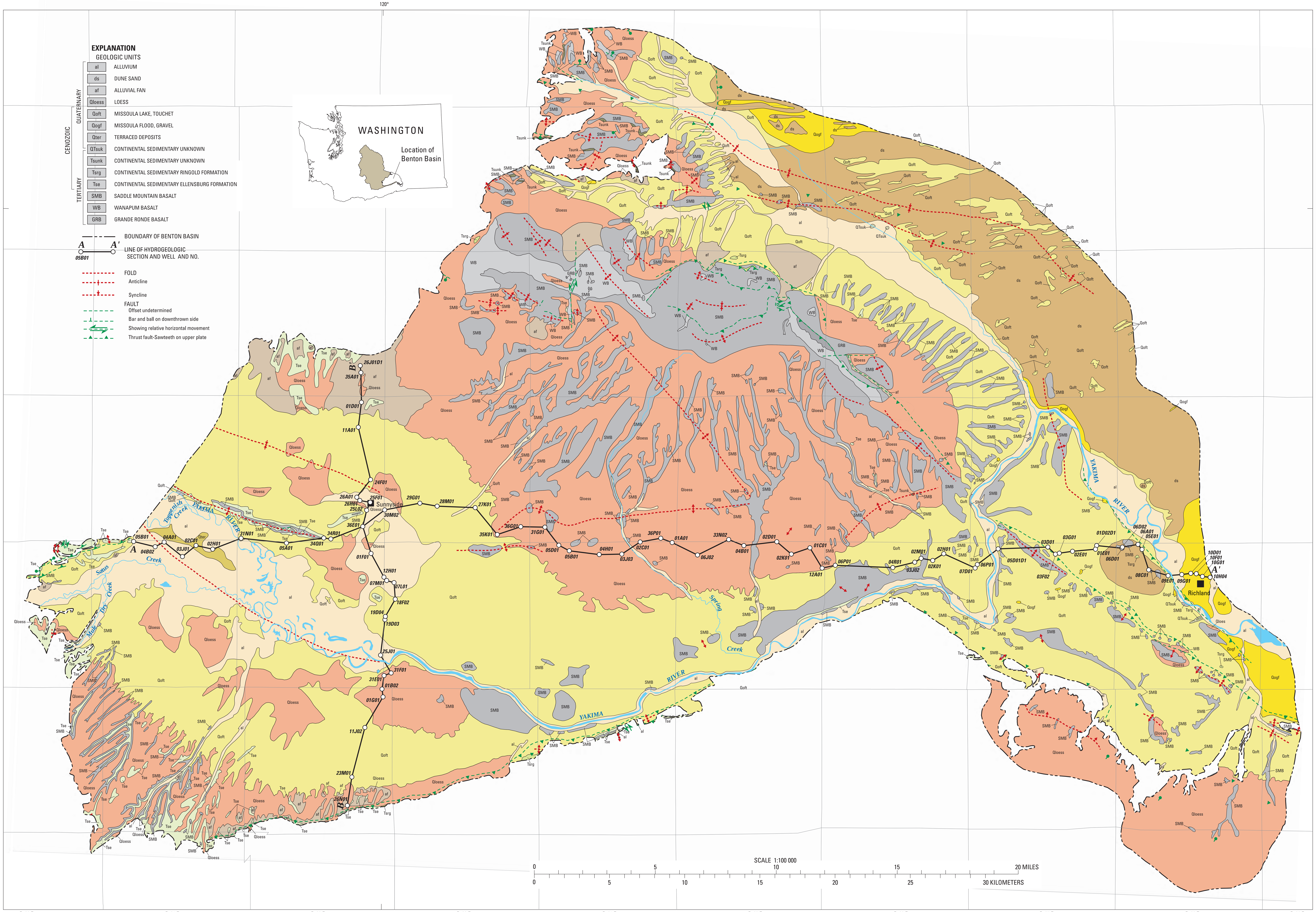

# Maps and Hydrogeologic Sections Showing Surficial Geology, Extent and Thickness of Basin-fill Deposits, Hydrogeologic Units, and Locations of Selected Wells in the Toppenish Basin, Yakima River Basin, Washington

By
Myrtle A. Jones, John Vaccaro, and Anni M. Watkins
2006

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

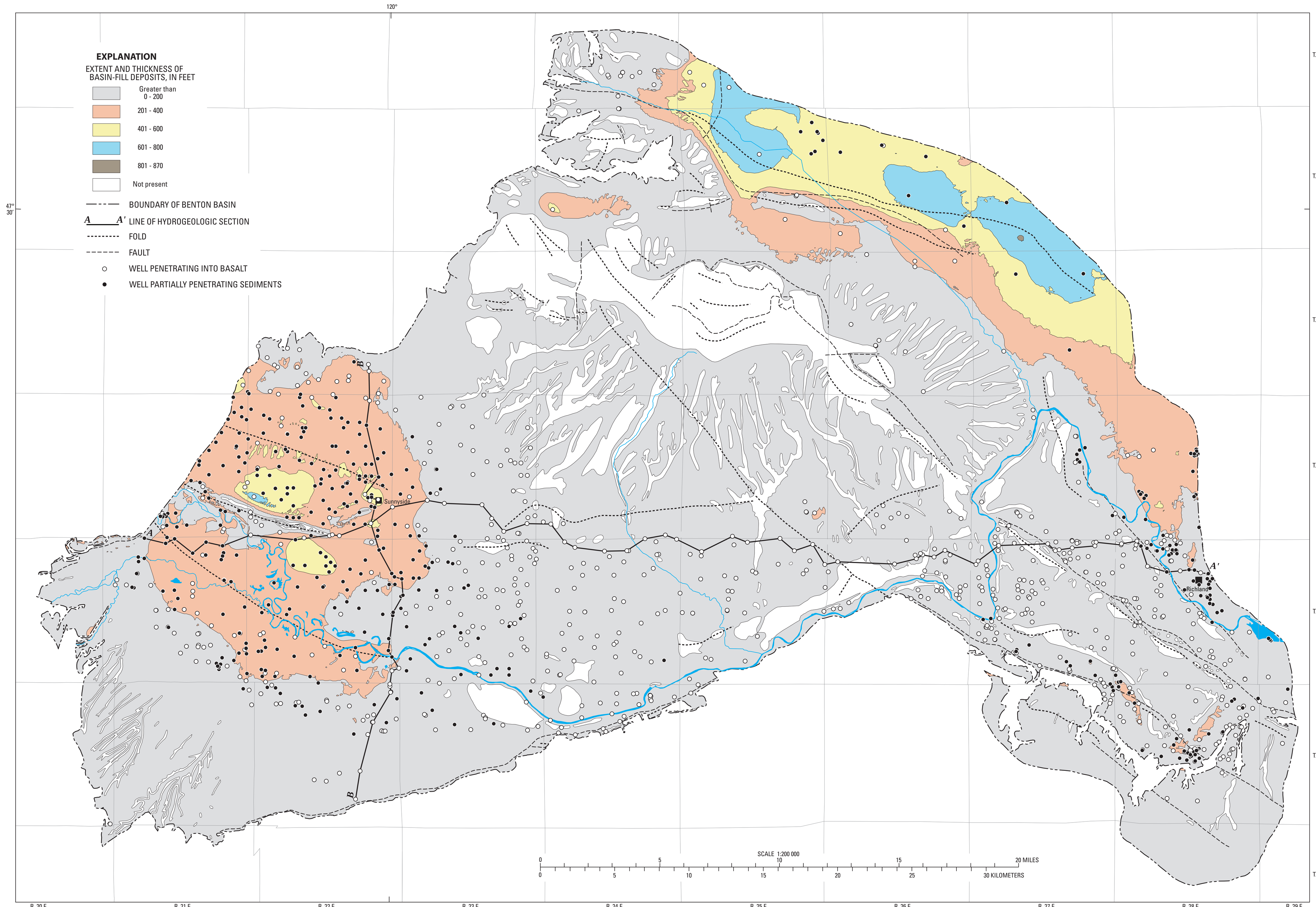
Prepared in cooperation with the
BUREAU OF RECLAMATION, WASHINGTON STATE DEPARTMENT OF ECOLOGY, AND THE YAKAMA NATION

SCIENTIFIC INVESTIGATIONS REPORT 2006–5116
Surficial geology and selected wells, Benton Basin—PLATE 6, Sheet 1
Jones, M.A., and others, 2006, Hydrogeologic Framework of Sedimentary Deposits in Six Structural Basins, Yakima River Basin, Washington




# Map Showing Surficial Geology and Locations of Selected Wells in the Benton Basin, Yakima River Basin, Washington

By
Myrtle A. Jones, John Vaccaro, and Anni M. Watkins
2006

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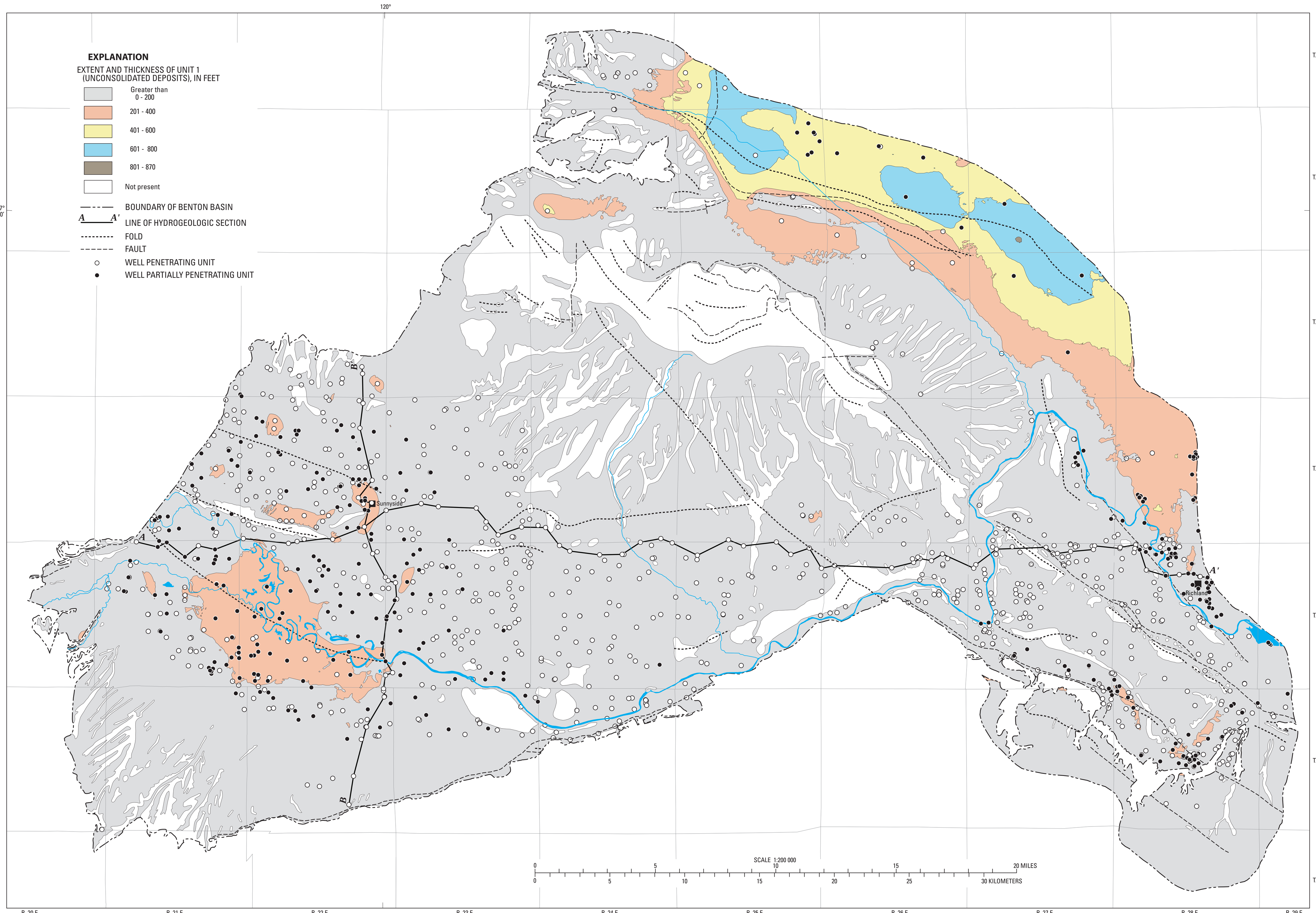
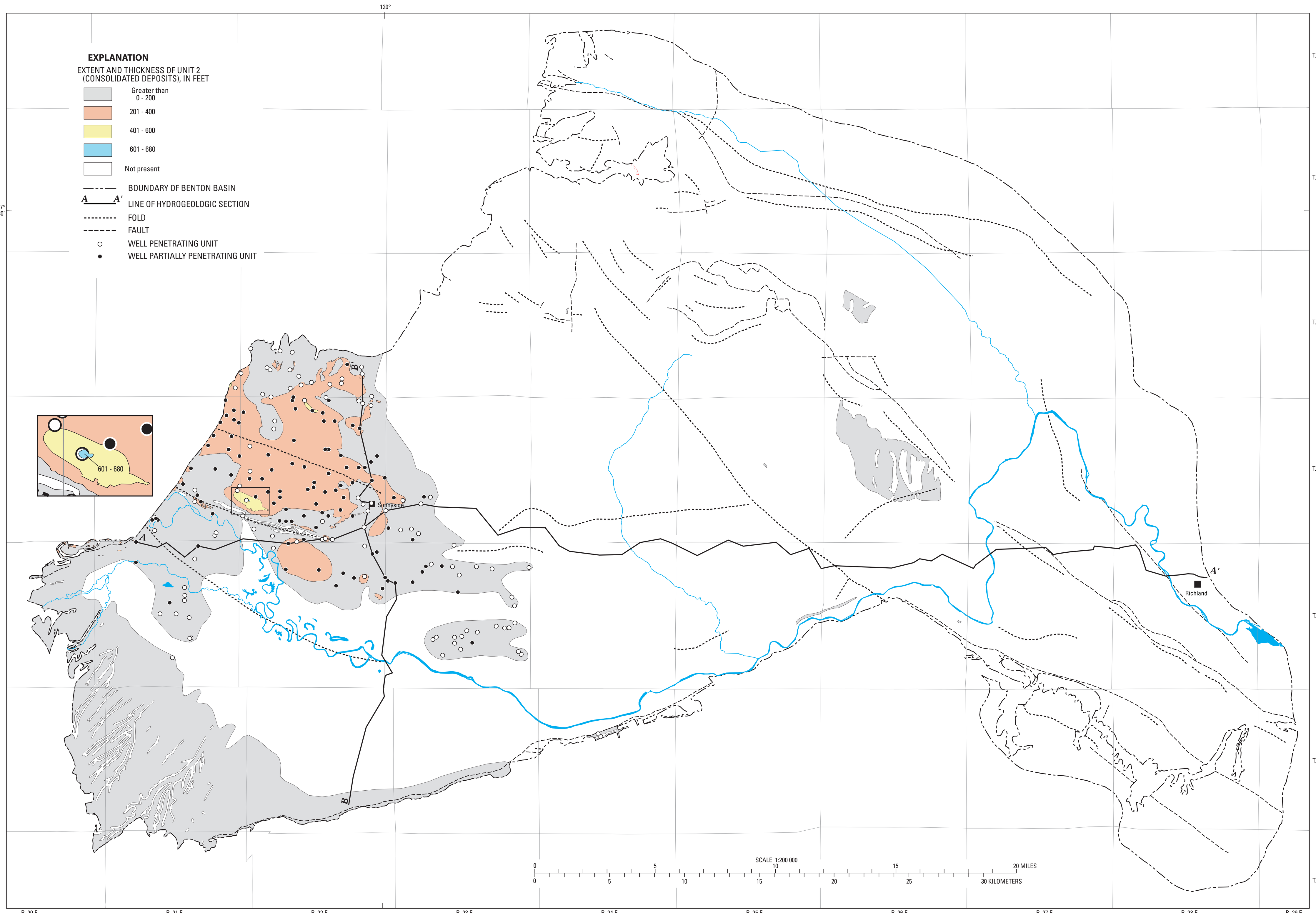
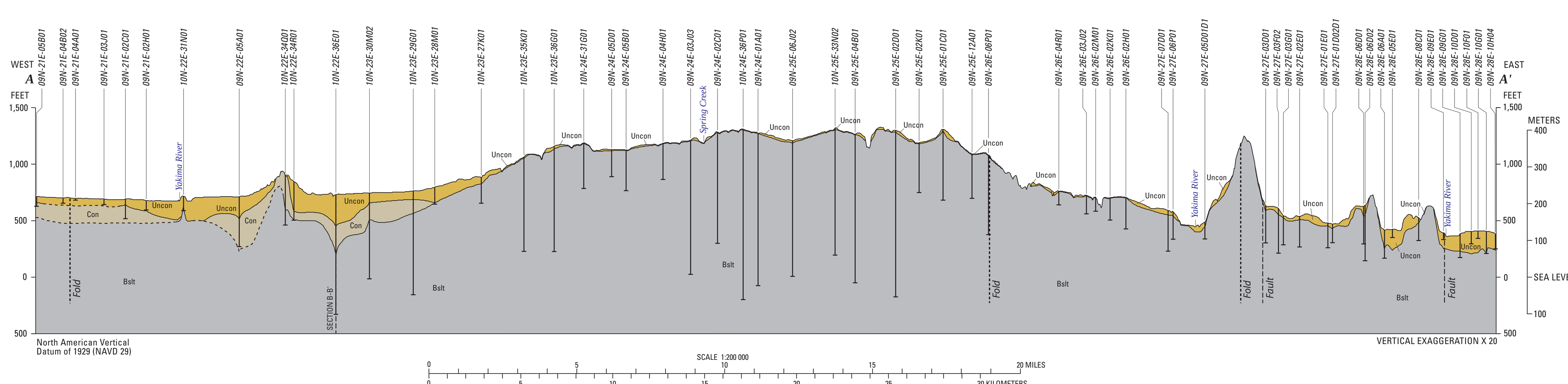
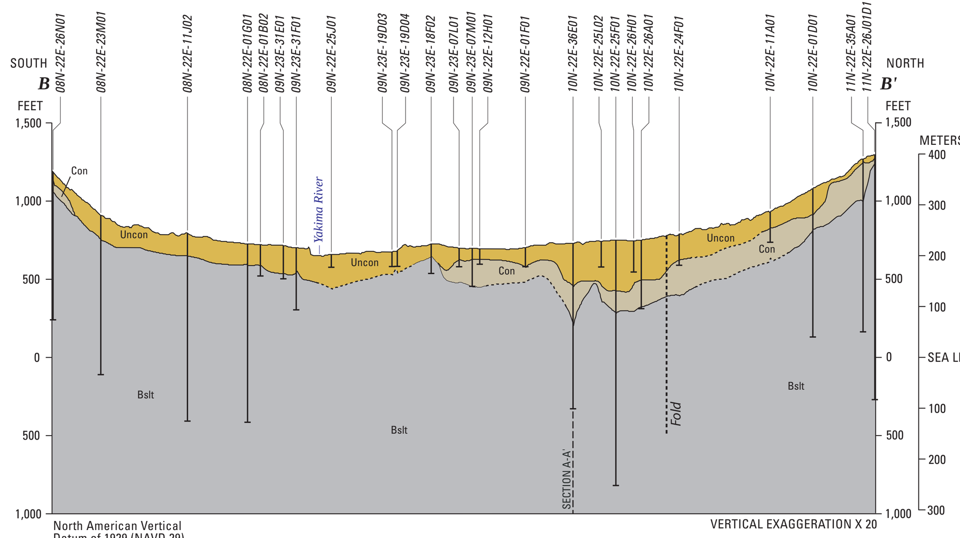


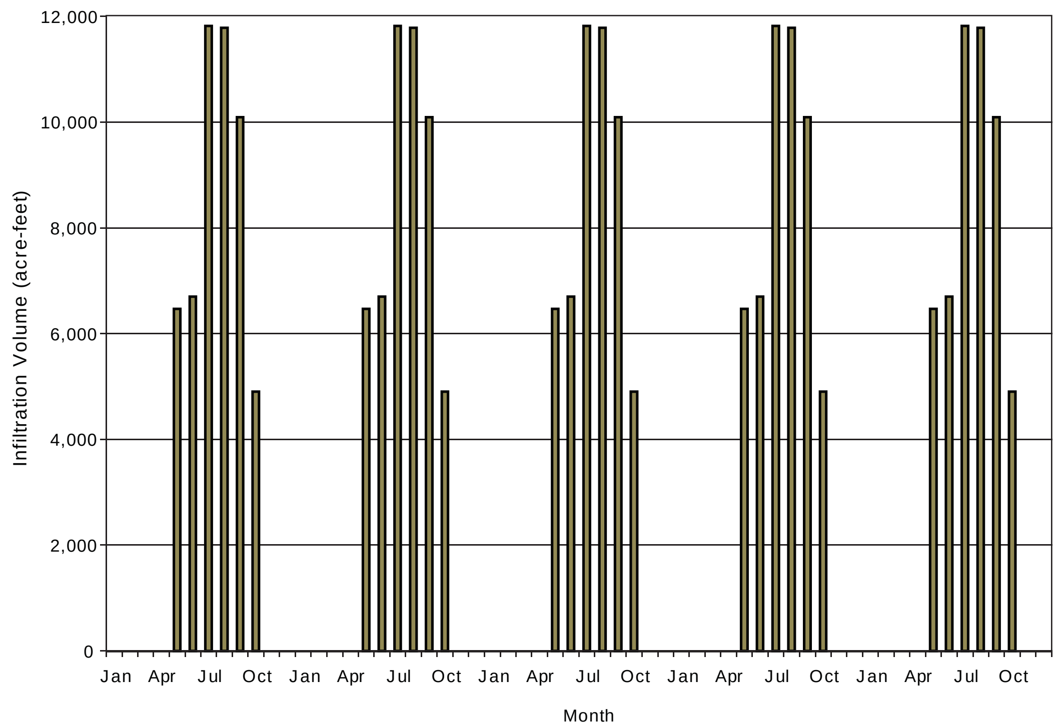




EXPLANATION
HYDROGEOLOGIC UNITS
- Uncon — UNIT 1 (Unconsolidated)
- Con — UNIT 2 (Consolidated)
- Bslt — BASALT
- HYDROGEOLOGIC CONTACT—Dashed where inferred
- WELL AND NO.


# Maps and Hydrogeologic Sections Showing Extent and Thickness of Basin-fill Deposits, Hydrogeologic Units, and Locations of Selected Wells in the Benton Basin, Yakima River Basin, Washington

By
Myrtle A. Jones, John Vaccaro, and Anni M. Watkins
2006

# APPENDIX B

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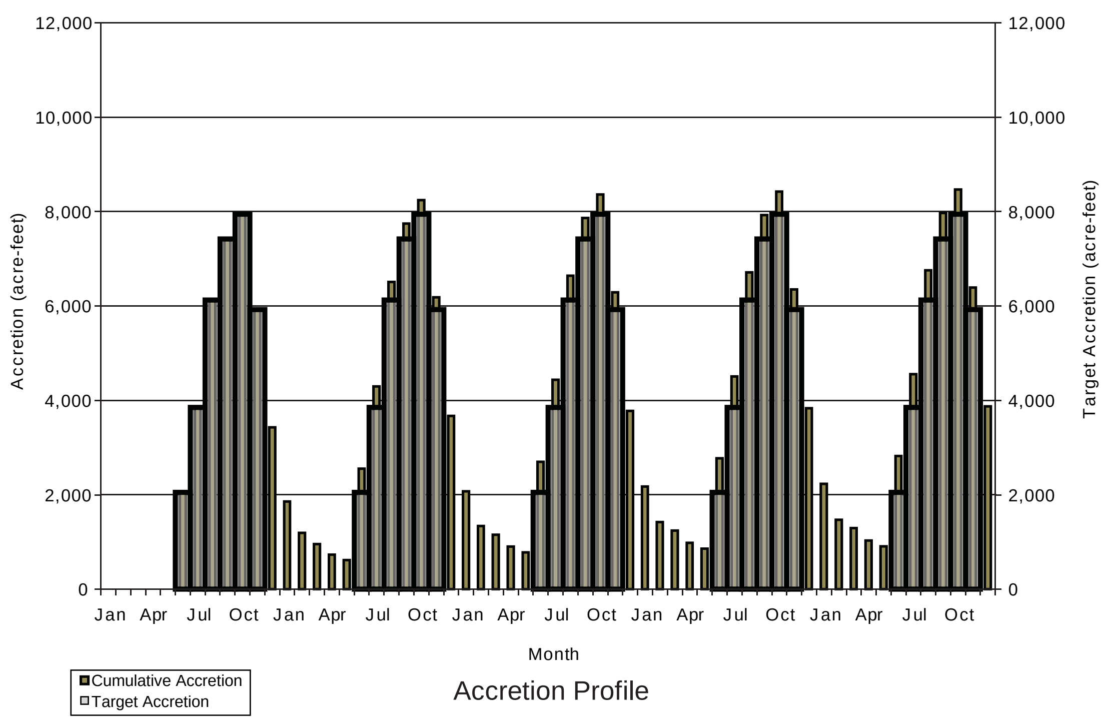



Accretion Profile

*Note:*
*The cumulative accretion for each month is composed of the accretion from previous months of infiltration. The carry-over of accretion from one year to another results in the accretion exceeding the target accretion in years 2*

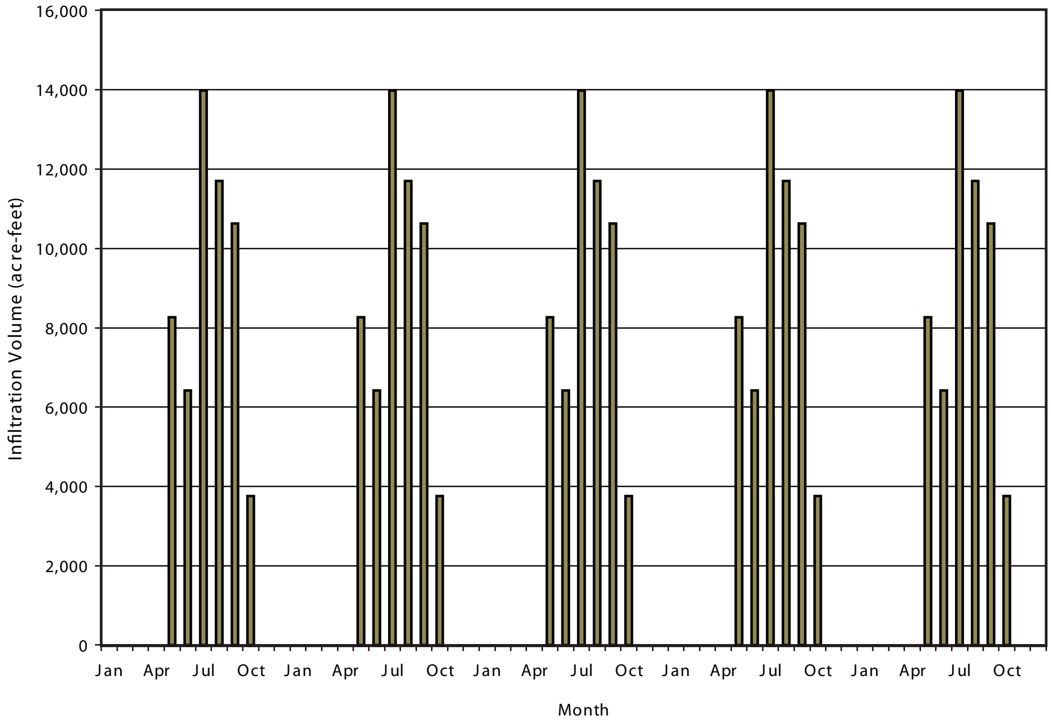
FIGURE **B-1**

**FIVE-YEAR INFILTRATION AND CUMULATIVE ACCRETION PROFILES ABOVE PARKER GAUGE WITH A STREAM DEPLETION FACTOR OF 30 DAYS**

ANCHOR/YAKIMA RVR BASIN STORAGE/WA



**Golder Associates**

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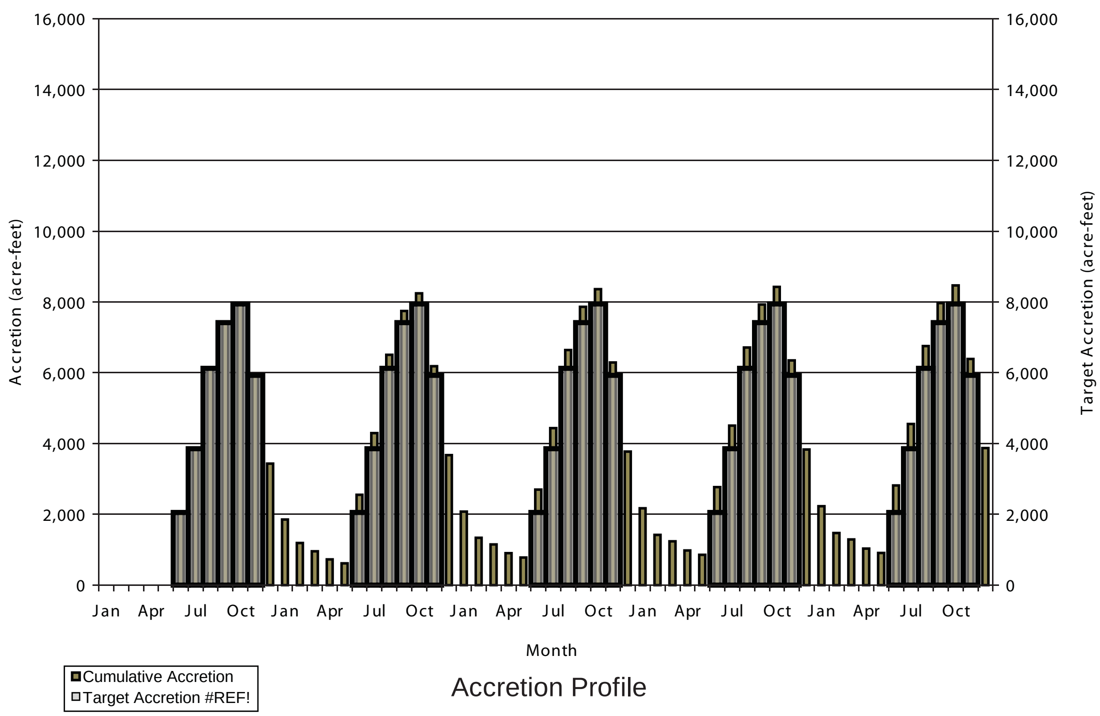



Accretion Profile

*Note:*
*The cumulative accretion for each month is composed of the accretion from previous months of infiltration. The carry-over of accretion from one year to another results in the accretion exceeding the target accretion in years 2 through 5.*

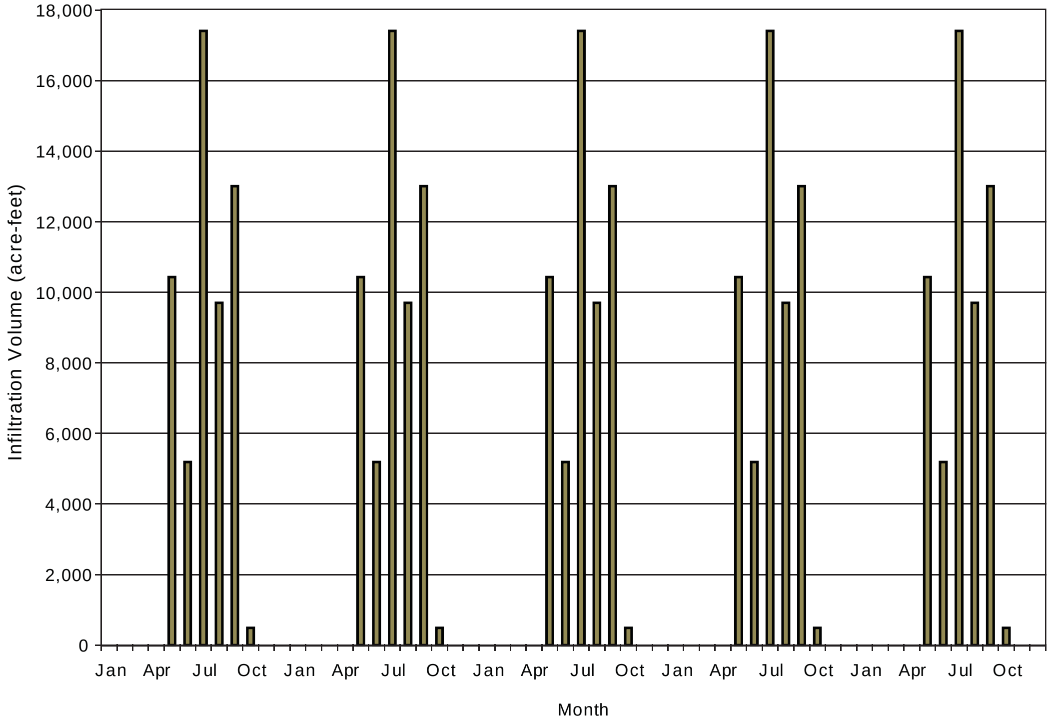
FIGURE **B-2**

**FIVE-YEAR INFILTRATION AND CUMULATIVE ACCRETION PROFILES ABOVE PARKER GAUGE WITH A STREAM DEPLETION FACTOR OF 40 DAYS**

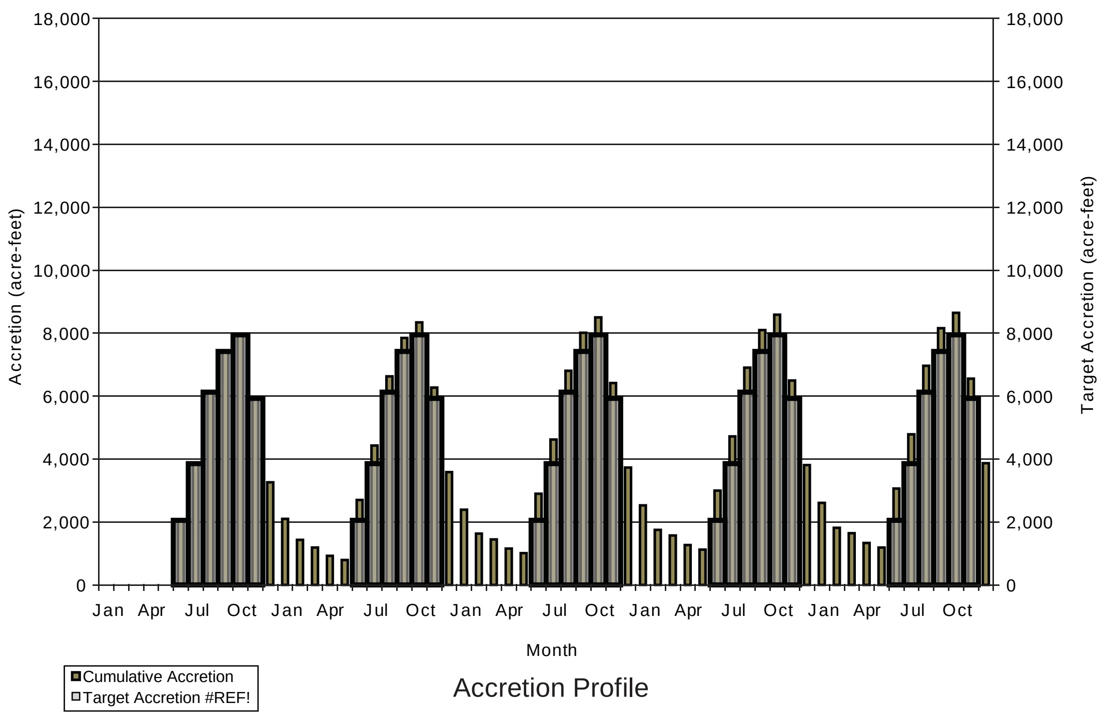
ANCHOR/YAKIMA RVR BASIN STORAGE/WA



**Golder Associates**




Infiltration Profile



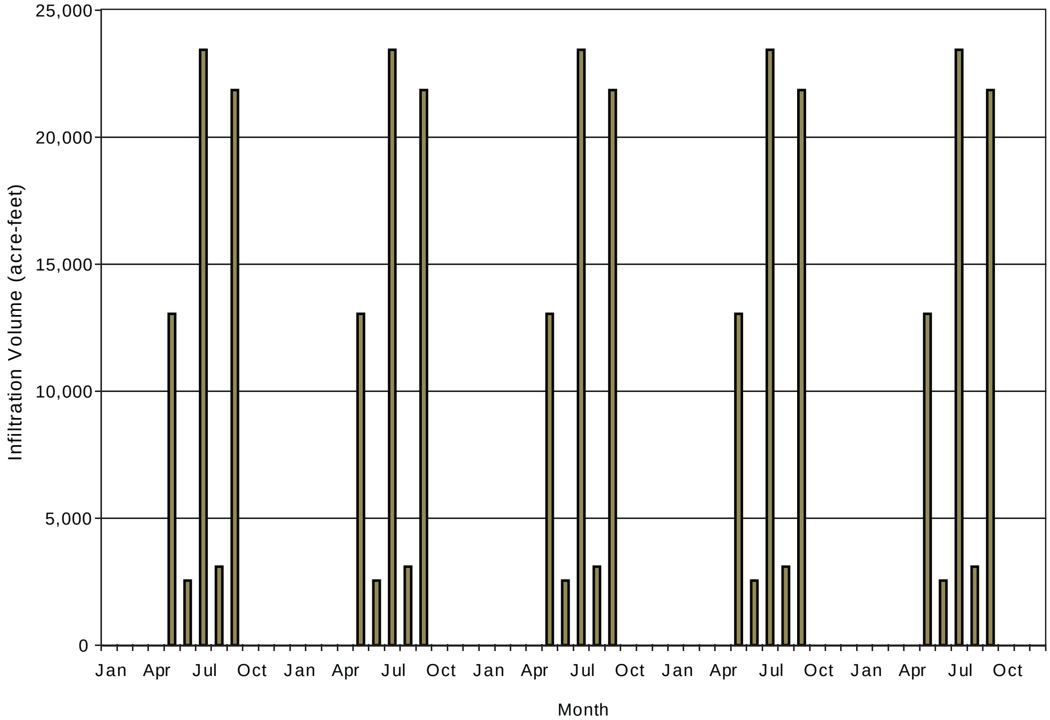

Accretion Profile

*Note:*
*The cumulative accretion for each month is composed of the accretion from previous months of infiltration. The carry-over of accretion from one year to another results in the accretion exceeding the target accretion in years 2 through 5.*

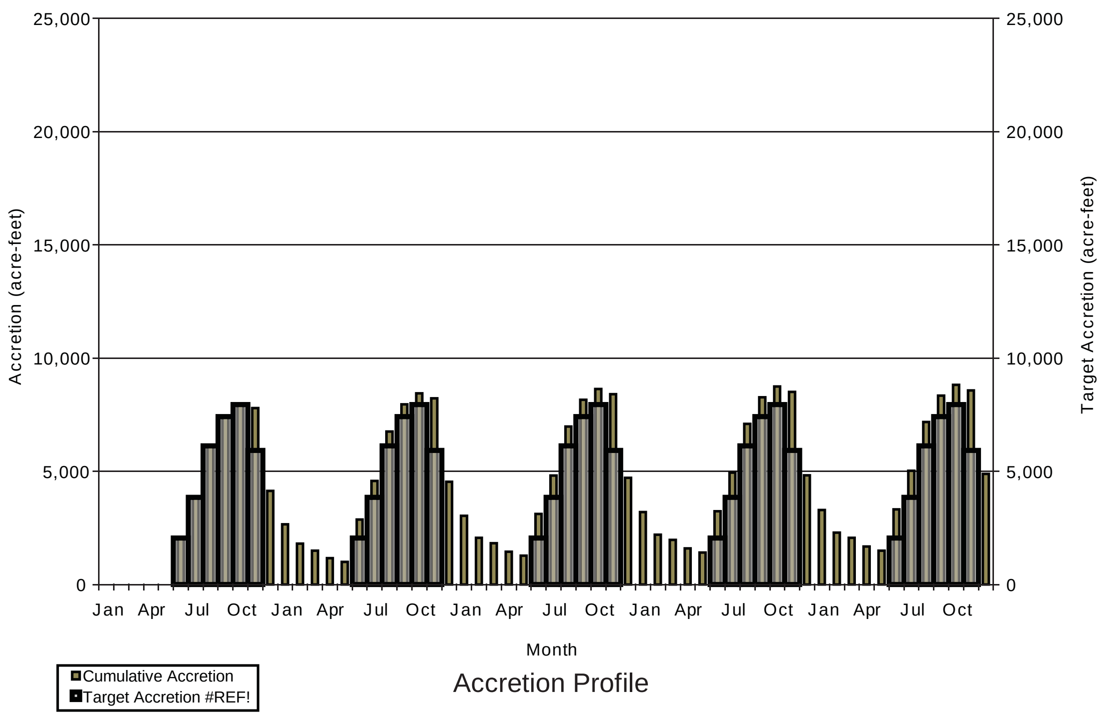
FIGURE **B-3**

**FIVE-YEAR INFILTRATION AND CUMULATIVE ACCRETION PROFILES ABOVE PARKER GAUGE WITH A STREAM DEPLETION FACTOR OF 50 DAYS**

ANCHOR/YAKIMA RVR BASIN STORAGE/WA




Infiltration Profile




Accretion Profile

*Note:*
*The cumulative accretion for each month is composed of the accretion from previous months of infiltration. The carry-over of accretion from one year to another results in the accretion exceeding the target accretion in years 2 through 5.*

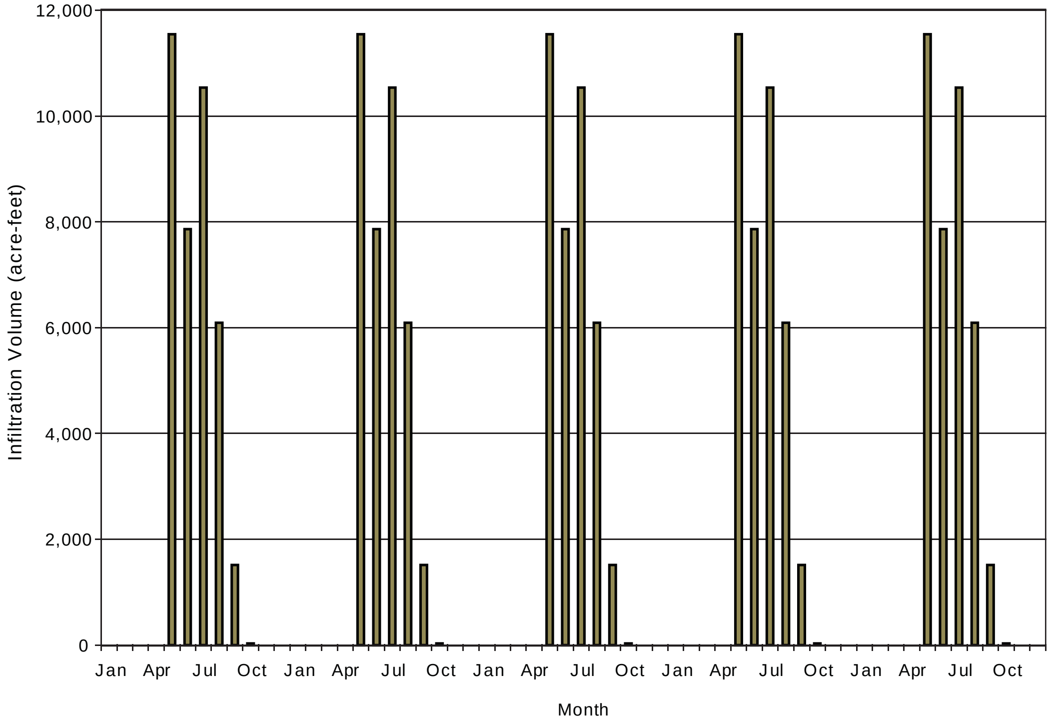
FIGURE **B-4**

**FIVE-YEAR INFILTRATION AND CUMULATIVE ACCRETION PROFILES ABOVE PARKER GAUGE WITH A STREAM DEPLETION FACTOR OF 60 DAYS**

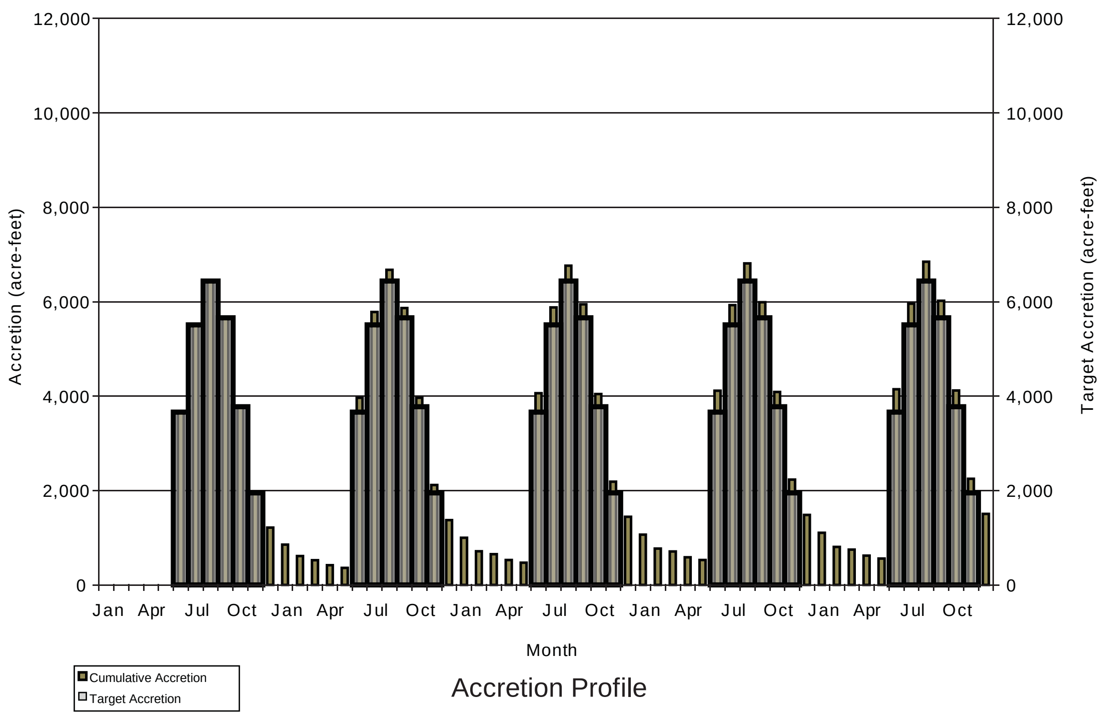
ANCHOR/YAKIMA RVR BASIN STORAGE/WA



**Golder Associates**




Infiltration Profile



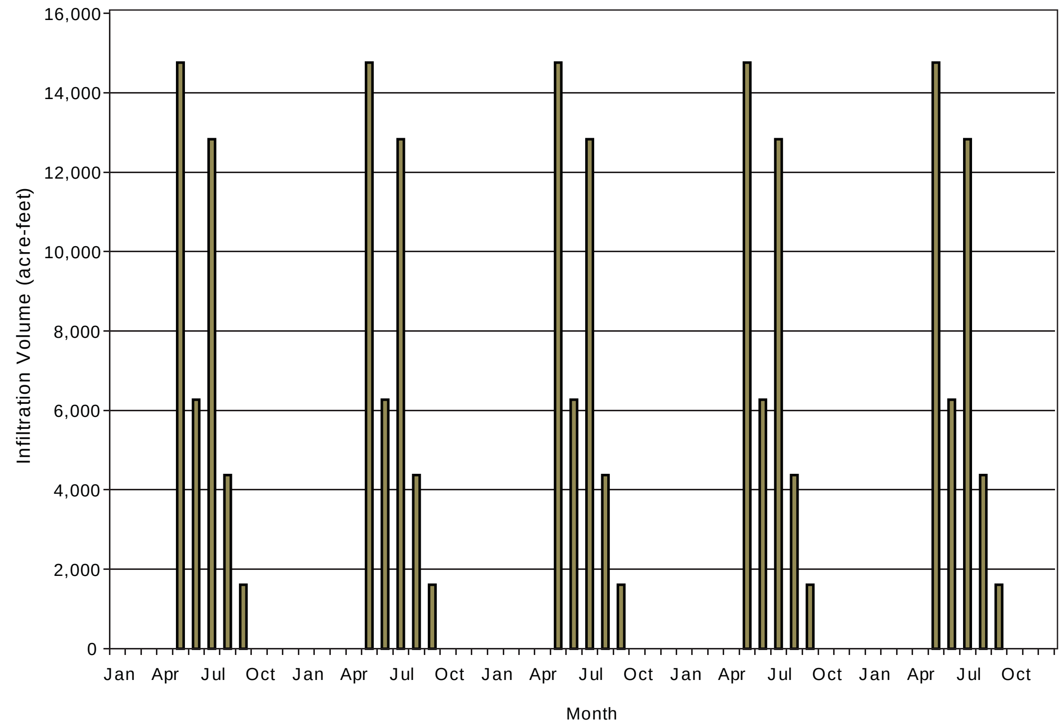

Accretion Profile

*Note:*
*The cumulative accretion for each month is composed of the accretion from previous months of infiltration. The carry-over of accretion from one year to another results in the accretion exceeding the target accretion in years 2 through 5.*

FIGURE **B-5**

**FIVE-YEAR INFILTRATION AND CUMULATIVE ACCRETION PROFILES BELOW PARKER GAUGE WITH A STREAM DEPLETION FACTOR OF 30 DAYS**

ANCHOR/YAKIMA RVR BASIN STORAGE/WA

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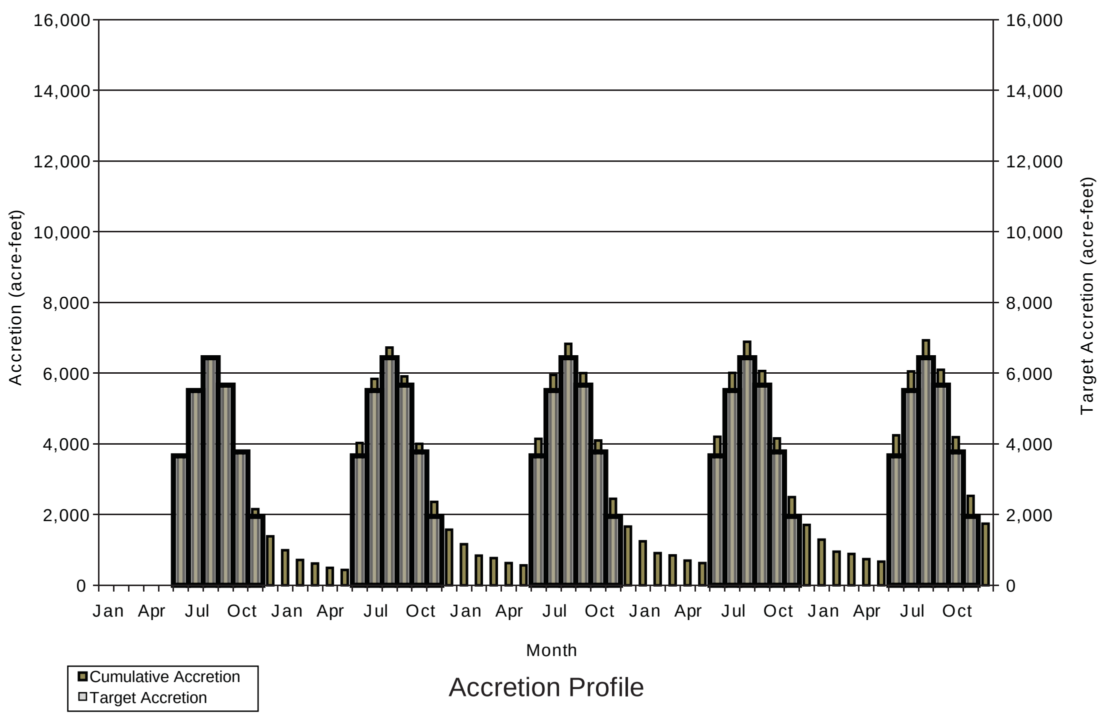



Accretion Profile

*Note:*
*The cumulative accretion for each month is composed of the accretion from previous months of infiltration. The carry-over of accretion from one year to another results in the accretion exceeding the target accretion in years 2 through 5.*

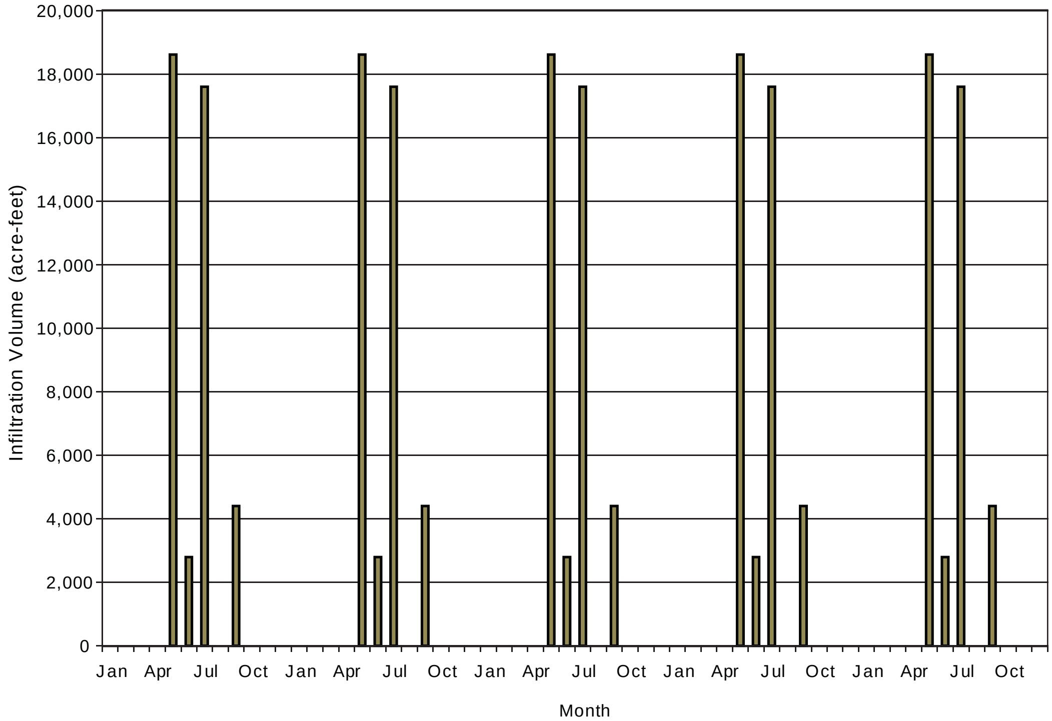
FIGURE **B-6**

**FIVE-YEAR INFILTRATION AND CUMULATIVE ACCRETION PROFILES BELOW PARKER GAUGE WITH A STREAM DEPLETION FACTOR OF 40 DAYS**

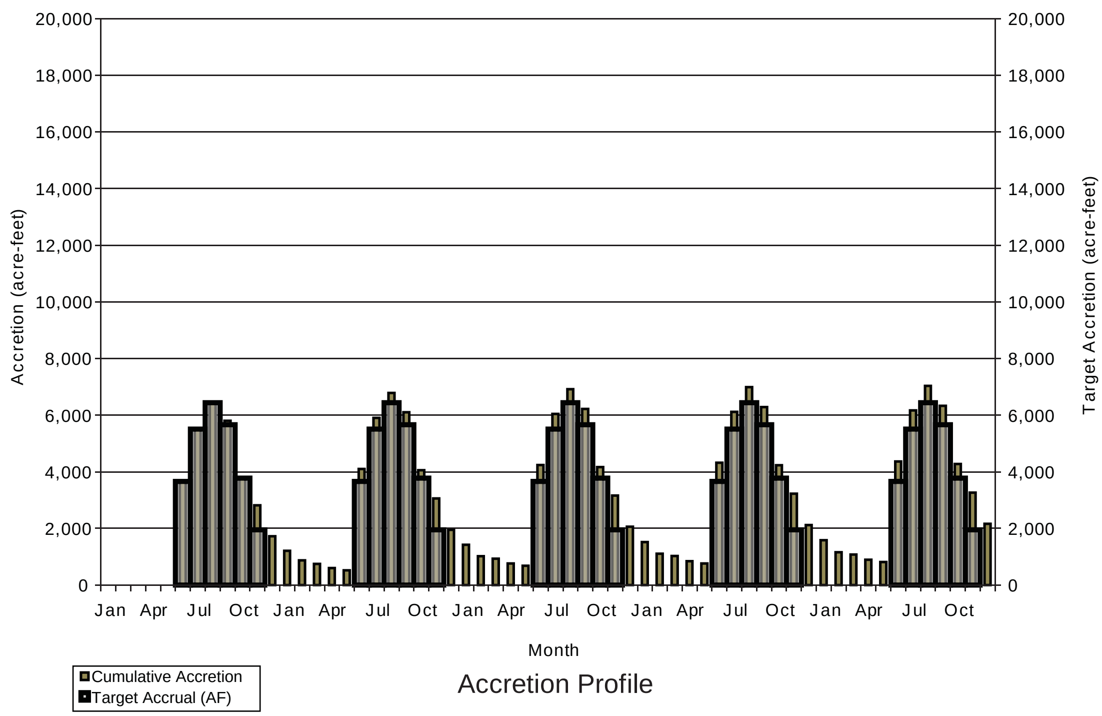
ANCHOR/YAKIMA RVR BASIN STORAGE/WA



**Golder Associates**




Infiltration Profile




Accretion Profile

*Note:*
*The cumulative accretion for each month is composed of the accretion from previous months of infiltration. The carry-over of accretion from one year to another results in the accretion exceeding the target accretion in years 2 through 5.*

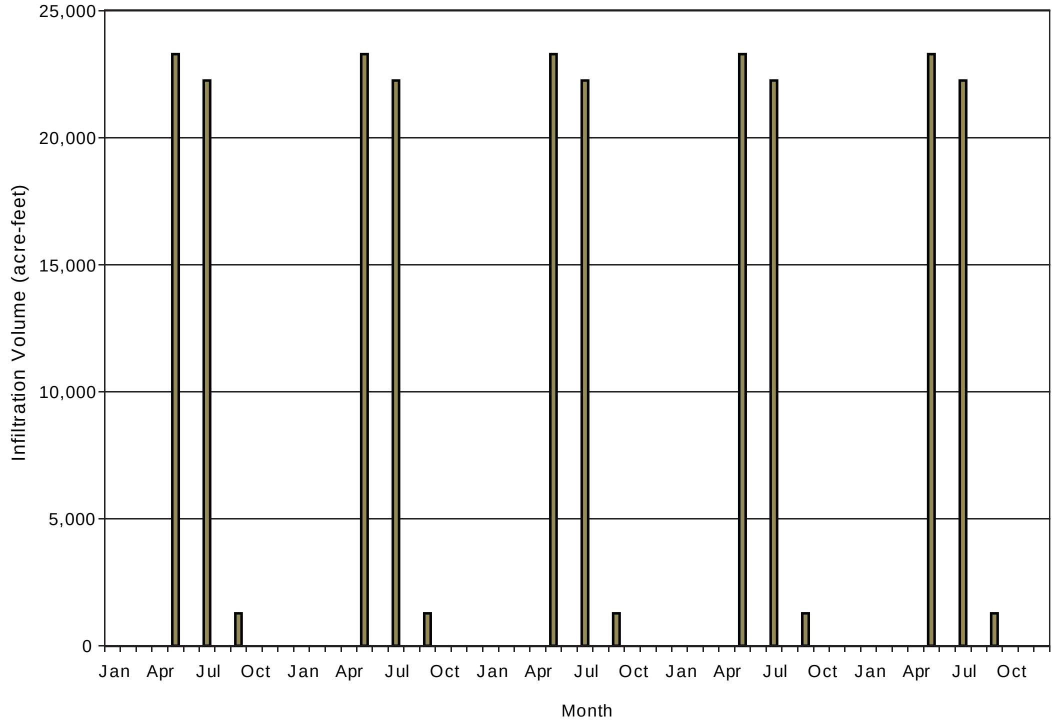
FIGURE **B-7**

**FIVE-YEAR INFILTRATION AND CUMULATIVE ACCRETION PROFILES BELOW PARKER GAUGE WITH A STREAM DEPLETION FACTOR OF 50 DAYS**

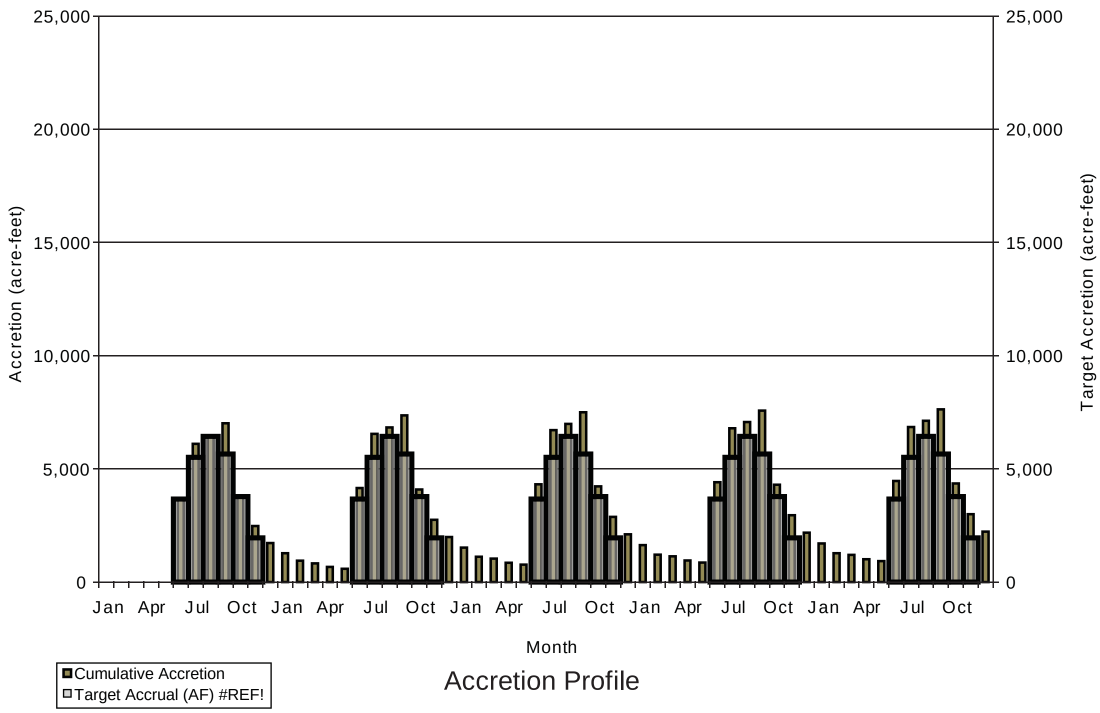
ANCHOR/YAKIMA RVR BASIN STORAGE/WA



**Golder Associates**




Infiltration Profile




Accretion Profile

*Note:*
*The cumulative accretion for each month is composed of the accretion from previous months of infiltration. The carry-over of accretion from one year to another results in the accretion exceeding the target accretion in years 2 through 5.*

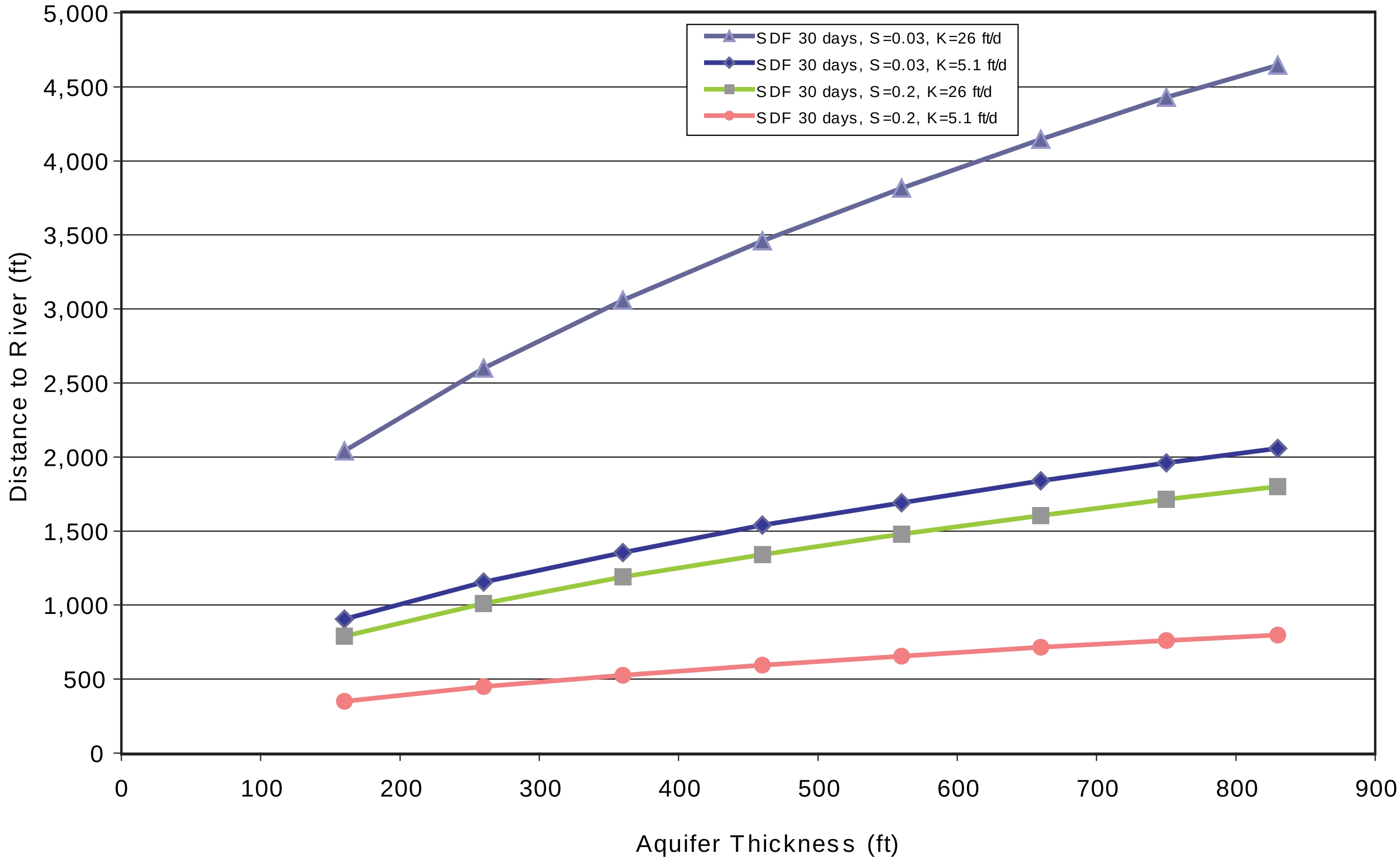
FIGURE **B-8**

**FIVE-YEAR INFILTRATION AND CUMULATIVE ACCRETION PROFILES BELOW PARKER GAUGE WITH A STREAM DEPLETION FACTOR OF 60 DAYS**

ANCHOR/YAKIMA RVR BASIN STORAGE/WA



**Golder Associates**




*Note:*
*SDF = stream depletion factor; ft/d = feet per day*
*1. The stream depletion factor determines the timing and volume of stream accretion from a infiltration pond. The stream depletion factor is a function of aquifer properties (transmissivity and specific yield) and distance from the stream. These lines capture the relationship between aquifer thickness and distance from the stream within the range of aquifer properties in the Yakima Basin that would result in a stream depletion factor of 30 days.*

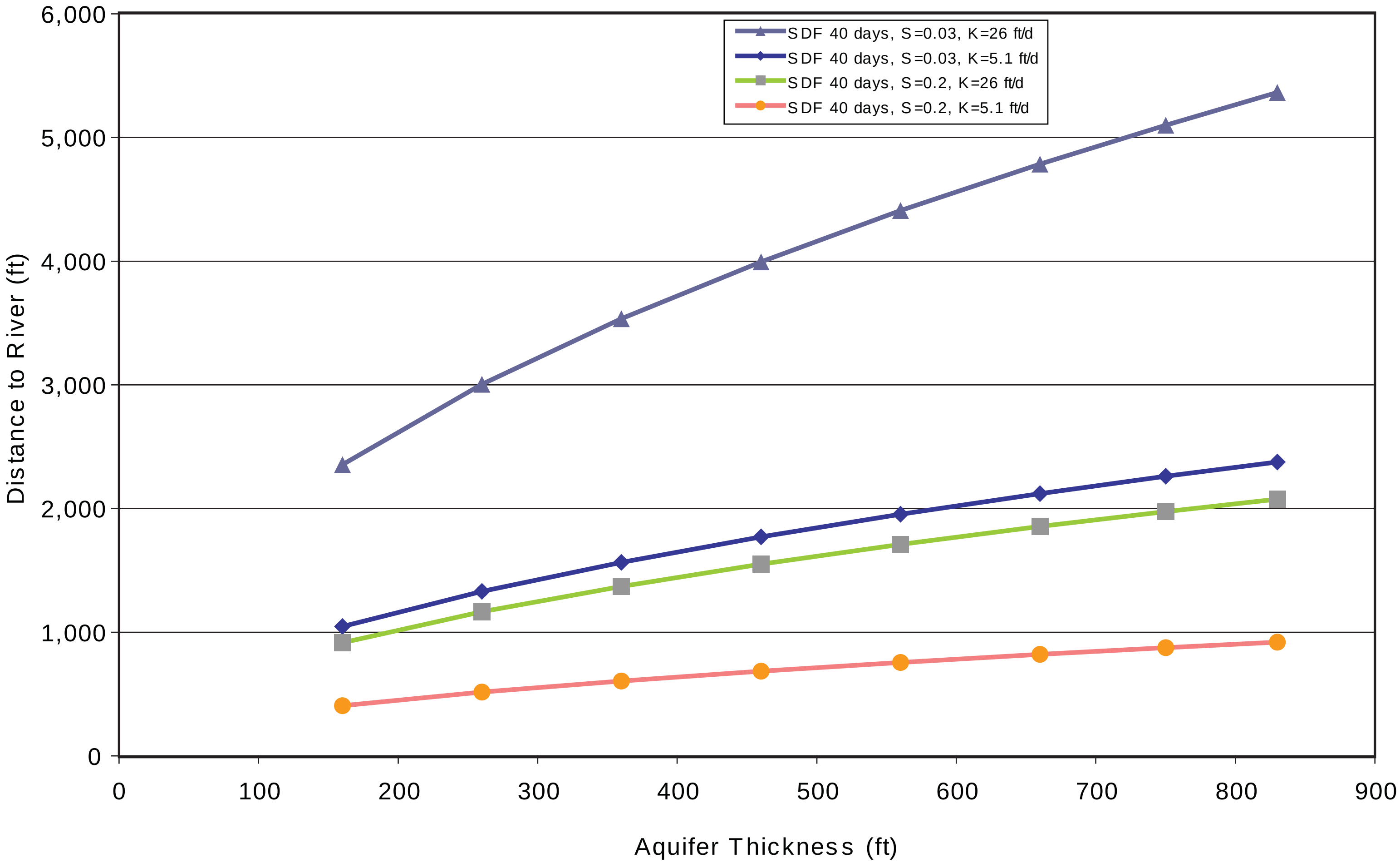
FIGURE **B-9**

**RELATIONSHIP BETWEEN DISTANCE AND THICKNESS NEEDED TO ACHIEVE A STREAM DEPLETION FACTOR OF 30 DAYS**

ANCHOR/YAKIMA RVR BASIN STORAGE/WA



**Golder Associates**




*Note:*
*SDF = stream depletion factor; ft/d = feet per day*
*1. The stream depletion factor determines the timing and volume of stream accretion from a infiltration pond. The stream depletion factor is a function of aquifer properties (transmissivity and specific yield) and distance from the stream. These lines capture the relationship between aquifer thickness and distance from the stream within the range of aquifer properties in the Yakima Basin that would result in a stream depletion factor of 30 days.*

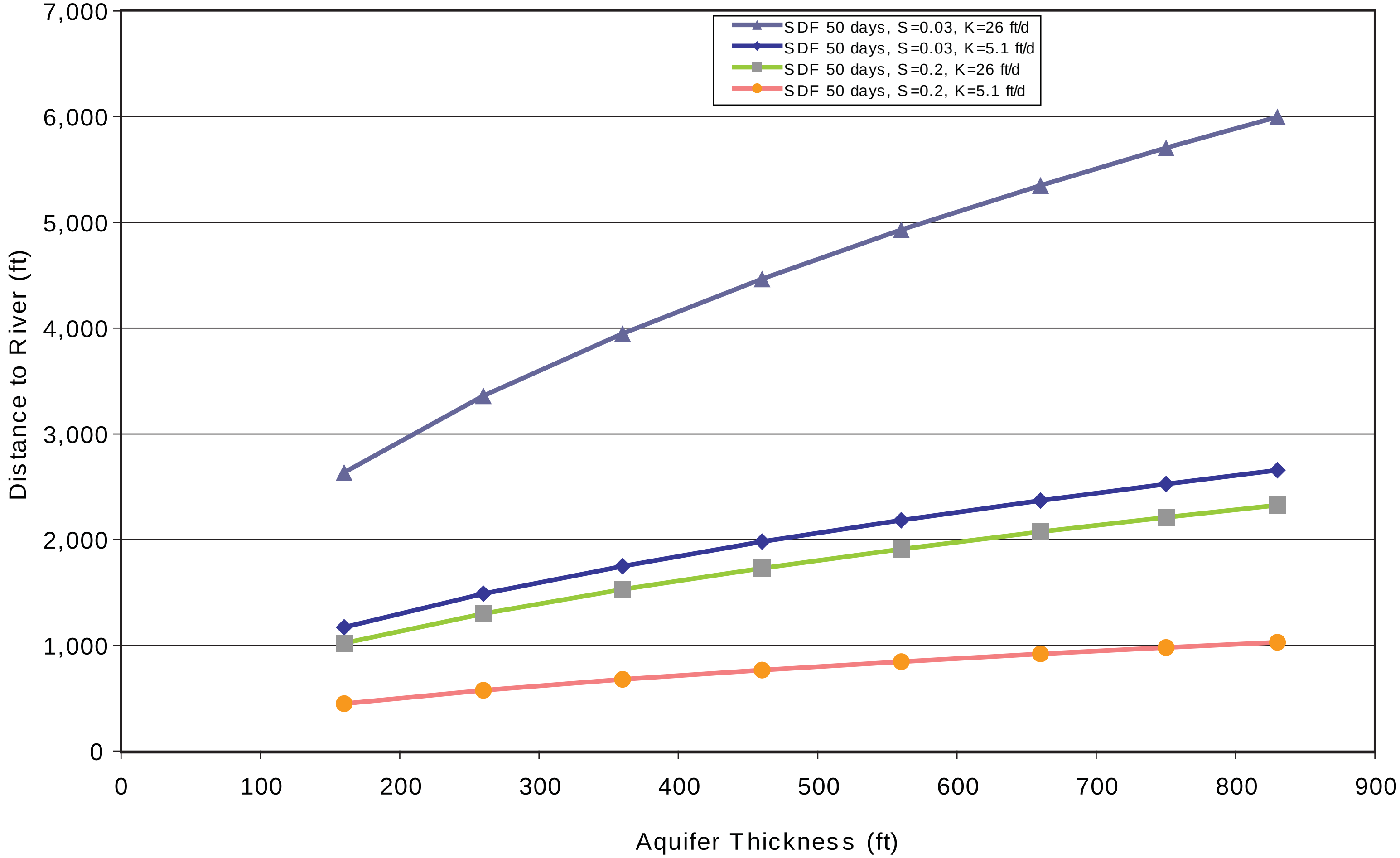
FIGURE **B-10**

**RELATIONSHIP BETWEEN DISTANCE AND THICKNESS NEEDED TO ACHIEVE A STREAM DEPLETION FACTOR OF 40 DAYS**

ANCHOR/YAKIMA RVR BASIN STORAGE/WA



**Golder Associates**




*Note:*
*SDF = stream depletion factor; ft/d = feet per day*
*1. The stream depletion factor determines the timing and volume of stream accretion from a infiltration pond. The stream depletion factor is a function of aquifer properties (transmissivity and specific yield) and distance from the stream. These lines capture the relationship between aquifer thickness and distance from the stream within the range of aquifer properties in the Yakima Basin that would result in a stream depletion factor of 30 days.*

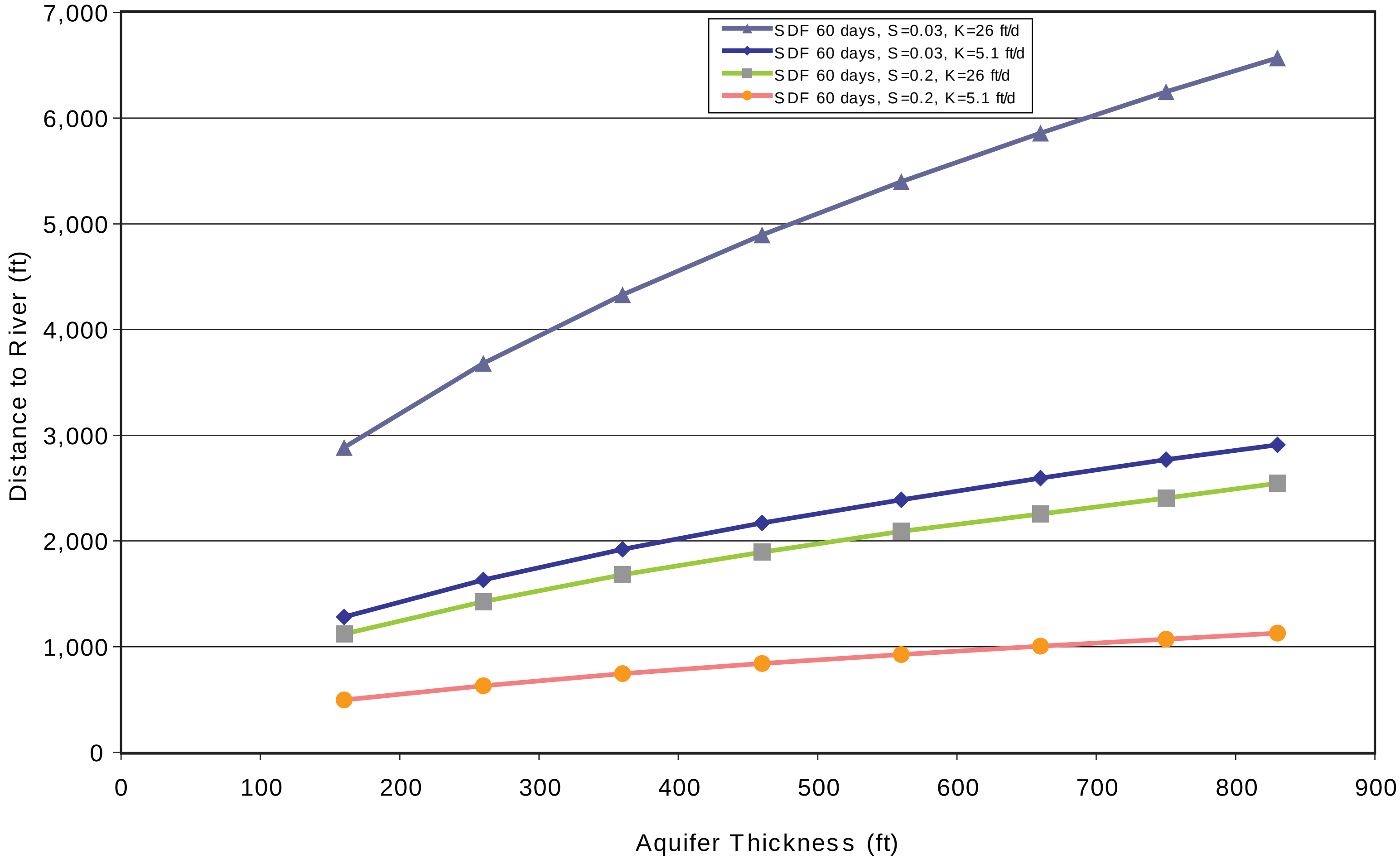
FIGURE **B-11**

**RELATIONSHIP BETWEEN DISTANCE AND THICKNESS NEEDED TO ACHIEVE A STREAM DEPLETION FACTOR OF 50 DAYS**

ANCHOR/YAKIMA RVR BASIN STORAGE/WA



**Golder Associates**




*Note:*
*SDF = stream depletion factor; ft/d = feet per day*
*1. The stream depletion factor determines the timing and volume of stream accretion from a infiltration pond. The stream depletion factor is a function of aquifer properties (transmissivity and specific yield) and distance from the stream. These lines capture the relationship between aquifer thickness and distance from the stream within the range of aquifer properties in the Yakima Basin that would result in a stream depletion factor of 30 days.*

FIGURE **B-12**
**RELATIONSHIP BETWEEN DISTANCE AND THICKNESS NEEDED TO ACHIEVE A STREAM DEPLETION FACTOR OF 60 DAYS**
ANCHOR/YAKIMA RVR BASIN STORAGE/WA



**Golder Associates**

# APPENDIX C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**operations**

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- recharge program
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- recovery plans
- excess contracts

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## recharge program

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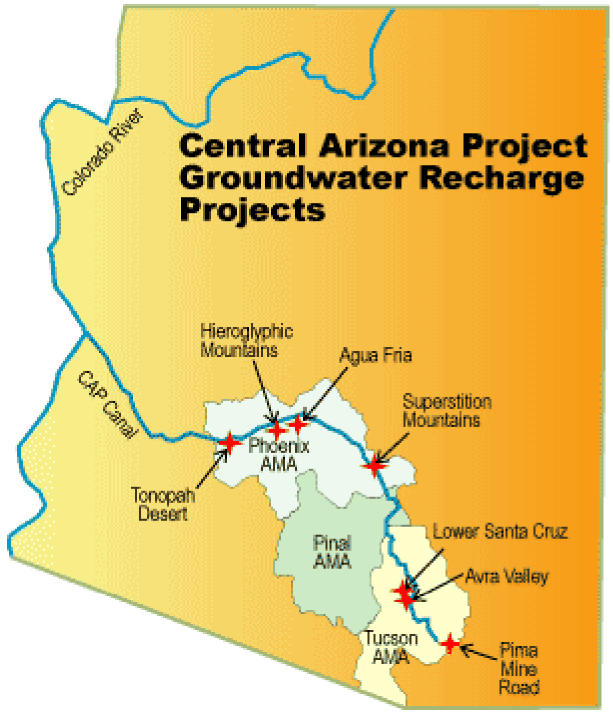


click on the map to view the projects



sit

CAP CENTRAL ARIZONA PROJECT

# EXECUTIVE SUMMARY



CAWCD has developed and currently operates five State Demonstration Recharge Projects with two additional projects under development with an expected completion date in late 2005. The Tucson Active Management Area (AMA) recharge facilities have a cumulative recharge capacity of 91,000 acre-feet per year and include the Avra Valley, Pima Mine Road and Lower Santa Cruz Recharge Projects. In the Phoenix AMA, there are two existing facilities; the Agua Fria and Hieroglyphic Mountains Recharge Projects, with a combined annual recharge capacity of 130,000 acre-feet. The two projects under development in the Phoenix AMA include the Tonopah Desert and Superstition Mountains Recharge Projects. These projects combined will add an additional 235,000 acre-feet of annual recharge capacity as shown in the following table. For a detailed description and photographs of each of the recharge facilities, go to "Projects".

PERMITTED RECHARGE CAPACITY

| Project Name | Year Complete | Permitted Capacity | Cumulative Capacity |
|---|---|---|---|
| Avra Valley | 1996-97 | 11,000 | 11,000 |
| Pima Mina Road | 1998-99 | 30,000 | 41,000 |
| Lower Santa Cruz | 2000 | 50,000 | 91,000 |
| Agua Fria | 2001 | 100,000 | 191,000 |
| Hieroglyphic Mountains | 2002 | 35,000 | 226,000 |
| Tonopah Desert | 2003 | 150,000 | 376,000 |
| Superstition Mountains | 2004 | 85,000 | 461,000 |

## Recharge Program Goals

Artificial groundwater recharge plays a critical role in the Central Arizona Water Conservation District (CAWCD) mission ..."to deliver the full allocation of Colorado River water to central Arizona in a reliable, cost effective and environmentally sound manner". Recharge is a long-established and effective water management tool that allows renewable surface water supplies, such as Colorado River water, to be stored underground now for recovery later during periods of reduced water supply.

In 1996, CAWCD completed its first recharge project in the Avra Valley located north of Tucson. The CAWCD Recharge Program has since expanded to include five operating projects and two new projects currently under development within CAWCD's service area. With the rapid expansion of CAWCD's Recharge Program, Arizona is now able to divert and put to use its full allocation of Colorado River water each year.

CAWCD's Recharge Program was established with the principal goal of protecting the economy and welfare of the State of Arizona by managing the reliability of its most valuable resource ...water. The water management benefits of recharge are numerous and include the following:

- Encourages the use of renewable water supplies instead of continued over-reliance on finite groundwater supplies;
- Mitigates impacts of groundwater overdraft including subsidence, water quality degradation and increased power costs for pumping water from greater depths;
- Firms Arizona's water supply by providing a "reserve" of water that can be recovered during prolonged drought or during interruption in the water delivery capability of the Central Arizona Project (CAP) aqueduct;
- Water stored underground in vast alluvial aquifers eliminates the need to construct costly surface reservoirs that are prone to excessive evaporation losses in Arizona's arid climate;
- Provides an alternative mechanism to deliver CAP water through recharge and recovery instead of constructing costly water treatment plants and distribution facilities;
- The quality of recharged surface water is improved by filtration through underlying sediments in a process known as soil aquifer treatment.

**Authority for CAWCD Recharge Program**

State legislation was adopted in 1971 that authorized the formation of the CAWCD to repay the federal government for the construction cost of the CAP, contract for delivery of Colorado River water and operate and maintain the CAP aqueduct. Subsequent statutory authority to conduct recharge activities was added to CAWCD's roles and responsibilities by the Arizona legislature beginning in the mid-1980's to include:

| Year | Authority Granted To CAWCD |
|---|---|
| 1986 | Authority to conduct feasibility studies for groundwater recharge and recovery projects. |
| 1987 | Authority to conduct underground storage and recovery activities |
| 1991 | Authority to acquire, develop, construct, operate and maintain State Demonstration Recharge Projects for underground storage of CAP water; creation of the State Water Storage Fund and authority to levy a property tax to develop State Demonstration Recharge Projects |
| 1993 | Authority to form and operate the Central Arizona Groundwater Replenishment District (CAGRD) |
| 1996 | Authority to dedicate funds from the State Water Storage Fund to the Arizona Water Banking Authority (AWBA). |
| 2000 | Authority to acquire real property for development of State Demonstration Recharge Projects through eminent domain. |

**CAWCD Recharge Program History**

Soon after receiving authority in 1986 to conduct recharge feasibility studies, CAWCD implemented two studies to identify favorable locations to develop recharge projects along the CAP aqueduct. Opportunities for Groundwater Recharge in Central Arizona, 1987, was a reconnaissance level feasibility study report that identified potential recharge sites along the entire length of the CAP between the Colorado River and Tucson. Butler Valley Underground Storage and Recovery Project, 1987, was a site-specific investigation report to assess the hydrologic feasibility of constructing a large-scale recharge project in the Butler Valley, an alluvial basin located in western Arizona. Although these studies investigated numerous potentially favorable sites, they did not result in development of a project.

In the early 1990's, CAWCD recharge efforts primarily focused on development of Groundwater Savings Facilities (GSF) also know as "in-lieu" or "indirect" recharge as a means of encouraging the direct use of CAP water instead of continued over-reliance on groundwater supplies. In general terms, a GSF is a water exchange authorized under State law where the operator of the GSF (typically an irrigation district) will substitute renewable surface water (CAP water) for groundwater that it has a legal right to pump. This substitution of surface water for groundwater essentially "saves" groundwater that would have been pumped and is legally considered analogous to direct recharge. The customer storing at a GSF receives long-term storage credits that can later be recovered and not counted as groundwater pumping.

Beginning in 1992, CAWCD acquired the necessary regulatory permits from the Arizona Department of Water Resources (ADWR) and entered into agreements with eleven different irrigation districts to deliver excess CAP water for agricultural irrigation in-lieu of pumping groundwater. In return, CAWCD earned long-term storage credits that can be recovered during future water supply shortages. Under this program between 1992 and 1999, CAWCD accrued approximately 645,000 acre-feet of long-term storage credits in its three-county service area.

In 1990, legislation passed authorizing CAWCD to develop State Demonstration Recharge Projects and established the State Water Storage Fund to finance development of these projects with revenues derived from a property tax collected in Pima and Maricopa Counties. The purpose of the State Demonstration Project statutes was to allow for construction of permanent, large-scale underground storage facilities for direct recharge of excess CAP water. These facilities provide a means of storing excess CAP water not currently used by CAP subcontractors for future recovery during periods of severe water shortages. State Demonstration Projects are also used for replenishment purposes by the CAGRD. Additionally, cities and private water companies utilize these projects for compliance with the State Assured Water Supply requirement. Finally, the Arizona Water Banking Authority (AWBA) stores water at State Demonstration Projects to firm the water supply of CAP municipal and industrial subcontractors against future shortages and for interstate water banking purposes.

Property taxes collected between 1991-1996, along with interest revenue, resulted in $33.7 million for the benefit of Maricopa County and $8.5 million for Pima County State Demonstration Projects. With the formation of the AWBA in 1996, CAWCD annually determines whether to direct revenues from the property tax to the AWBA to fund groundwater recharge and other AWBA activities. All property tax revenue collected since 1997 has been directed to the AWBA.

CAP CENTRAL ARIZONA PROJECT

# Avra Valley Recharge Project





## INTRODUCTION

Avra Valley Recharge Project (AVRP) was Central Arizona Project's (CAP) first recharge project. It was first conceived as part of the Northwest Tucson Active Management Area (AMA) Replenishment Program, a cooperative effort of the local water entities that began in 1994. Located in the northwest portion of the Tucson AMA, the project consists of approximately 11 acres of recharge basins. CAP constructed and began operating AVRP in July 1996 as a 2-year pilot project and permitted the facility as a full-scale project in March 1998. The project is located near the Marana Airport west of the Tangerine Road exit off I-10. It was developed and constructed with State Demonstration Project funds.

Water is pumped from the CAP canal utilizing two natural gas-powered engines into an open channel irrigation canal. The water is diverted from the irrigation canal into a main distribution box. The facility is divided into four separate basins that range from 1.8 to 3.5 acres in size. The flow is measured using individual v-notch weirs at each basin.

Since 1996, water has been stored at AVRP for the Arizona Water Banking Authority (AWBA), Central Arizona Groundwater Replenishment District, Metropolitan Domestic Water Improvement District, and the Town of Marana. In 2003, all the deliveries were on behalf of the AWBA.

Water delivered to Basin 3 at AVRP

**Project Facts**

- Permit Capacity: 11,000 AF per year
- Cost: $790,000
- Volume Stored Through April 2004: 44,149 AF
- Basins: Four basins ranging from 1.8 to 3.5 acres
- Total Acreage: 10.8 acres
- Location: T12S,R11E, Section 3 SW Corner
- Delivery Capacity: 12 cfs
- Pilot Operation: 1996-98
- Full Scale Startup; March 1998

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## FACILITY COMPONENTS

AVRP consists of four basins ranging in size from 1.8 to 3.5 acres for a total of 10.8 acres. The water is delivered to the project using two natural gas-powered canal-side pumps that are capable of pumping up to 11,000 gallons per minute each (approximately 25 cubic feet per second). The water is pumped into an open irrigation supply canal and conveyed approximately 1 mile from the CAP canal before being diverted into the project by manually adjusting a slide gate in the canal.

**Manual slide gate to divert water into recharge project**

The water that is diverted into the basins enters a single concrete distribution box where it is delivered to the individual basins. At each basin, a separate concrete distribution box containing a v-notch weir measures the flow before entering the basin. The water level in the v-notch weir is measured using a pressure transducer inside a stilling well and recorded every 15 minutes. Also, pressure transducers are installed in each basin to measure change in the water levels to ensure the basins do not overfill.

**V-notch weir with stilling wells at top of photograph**

All the information collected at the project is recorded at a central SCADA system that is powered by solar energy and uses Geomation Measurement and Control Systems for remote data acquisition. The data is collected at a central MCU and transmitted by radio to the

CAP Twin Peaks Pumping Plant where it is sent through the CAP microwave network back to CAP Headquarters.

**Solar powered remote data acquisition system at AVRP**

Lower Santa Cruz Recharge Project and AVRP are within the Federal Aviation Authority's (FAA) 10,000-foot radius of the Marana Northwest Regional Airport and, therefore, require mitigation to protect the airplanes from bird strikes. LSCRP, the larger of the two projects, employs the Phoenix Wailer that generates random noises to scare off loafing birds while at AVRP, passive bird mitigation is employed.

Passive bird mitigation at AVRP utilizing plastic-mounted owls

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## HYDROLOGY

The surficial geology in the immediate vicinity of the project site consists of Quaternary Recent Alluvium and the Quaternary Fort Lowell Formation. Geologic outcrops in the general vicinity include the Tortolita Mountains (located 5 miles northeast) and the Tucson Mountains (located 3 miles southeast). The Tortolita Mountains consist primarily of Cretaceous and Tertiary igneous rocks, and the Tucson Mountains consist primarily of Cretaceous igneous rocks.
The site is located within an alluvial basin within the Basin and Range Physiographic Province of southern Arizona in the Avra Valley groundwater basin. The alluvial deposits comprising the basin are the eroded remnants of the surrounding mountain ranges. The primary basin-fill deposits consist of (from youngest to oldest): Recent Alluvium (Quaternary), Fort Lowell Formation (Quaternary), and Tinaja beds (Tertiary).

Recent Alluvium: The Recent Alluvium occurs from ground surface to depths ranging from 32 to 84 feet. The Recent Alluvium consists of an upper interval of mostly fine to medium-grained floodplain deposits (7.5 to 30 feet thick), an intermediate interval of medium-grained stream deposits (0 to 11 feet thick), and a lower interval of coarse-grained gravelly stream deposits (16 to 56 feet thick).

Fort Lowell Formation: The Fort Lowell Formation consists of unconsolidated to poorly consolidated clayey, sandy gravel and clayey, gravelly sand with inter-bedded fine-grained intervals (ranging from 3 to 24 feet thick). Throughout most of the basin, the Fort Lowell Formation is 300-400 feet thick but, in the vicinity of the project, the formation is 250 to 275 feet thick.

Tinaja beds: The Tinaja beds are the principal water-bearing strata in the area. The beds are differentiated into three units: upper, middle, and lower. The upper Tinaja beds consist of unconsolidated to poorly cemented gravel to clayey silt; but in the uppermost part, the grain size is coarse and similar to the overlying Fort Lowell Formation. The middle Tinaja beds consist primarily of moderately cemented gypsiferous and anhydritic clayey silt and mudstone. The lower Tinaja beds consist of moderately to firmly cemented gravel and conglomerate to clayey silt and mudstone. The overall thickness of the Tinaja beds is estimated to exceed 1,500 feet.

The project is adjacent to the Santa Cruz River. Groundwater flows to the northeast paralleling the river. Depth to water was over 280 feet below ground level before operations began. Currently the depth to water is approximately 190 feet.

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## MONITORING AND REPORTING

The underground storage facility permit issued by the ADWR requires that each project operator monitor responses from the recharge operations on the regional water level and water quality. The data must be submitted in the form of annual data reports. The LSCRP and AVRP are within 1-quarter mile of each other and share the same monitoring network. Therefore, in 2002, ADWR agreed that the two projects could be combined for reporting purposes.

**Aerial view showing the proximity of AVRP in the foreground and LSCRP in the background**

The monitoring network for both projects includes 7 piezometers at each site for a total of 14 piezometers, 1 on-site monitor well at each site, and 7 off-site monitor wells. Also, the water levels in each basin are monitored to ensure the basins do not over-fill.

CAP staff collects water levels on a monthly basis with an electric sounder. The two on-site wells, LSCMW-1 and AVMW-1, are equipped with continuous water level dataloggers. The monitor wells, except for the Tangerine Landfill monitor wells, have an alert level that the mounding groundwater must be deeper than 20 feet below ground level. The Tangerine Landfill wells, Tang-1, Tang-2, and Tang-4, have alert levels set at 105 feet below ground level to protect the invert of the landfill from being saturated.

Water quality samples are collected and analyzed for the constituents listed in the USF Permit from monitor wells LSCMW-1, AVMW-1, SC-09, and SC-10. The alert levels are set as the NAWQS level for each constituent. Measured water quality components include inorganic and organic constituents, including pesticides and herbicides.

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## OPERATIONS

AVRP began operations in June 1996 as CAP's first recharge project and consists of four basins totaling 10.8 acres. CAP entered into a Water Transportation Agreement with BKW Farms, Inc. (BKW) to wheel or transport water through BKW's agricultural irrigation canal system to the recharge basins. The flows are measured at the turnout of the CAP canal with a McCrometer propeller flow meter, and the flows that are diverted into the recharge basins are measured with v-notch weirs at the inlet to each basin.

With only 10.8 acres of basins, rotating basins is not practical, so when the project is operational, all the basins are receiving water. Infiltration rates vary from basin to basin. Basins 1 (SE), 2 (SW), and 3 (NE) average from 2.1 to 3.5 feet/day with Basin 4 (NW) averaging < 1 foot/day. A clay layer that impedes its infiltration rate underlies basin 4.

**Water delivered to Basin 3**

During 2003, due to drought conditions and high customer demands for agricultural water deliveries, the project was shut down for the first 7 months of the year. The AWBA is currently the only entity storing water at this facility.

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## MAINTENANCE

The maintenance schedule is dictated by observing the infiltration rates of the basins. With only 10.8 acres of basins, AVRP is operated at full capacity with no basin rotation possible. As the infiltration rates decrease, the methods used to rejuvenate the basins vary. When the infiltration rates first begin to degrade a single basin, drying is utilized to allow the fine-grained clogging material to dry and form desiccation (mud) cracks. Spring-tooth harrows are also used to break up the clogging layer. Finally, when the clogging layer becomes too thick, the basins are scraped to physically remove sediment using a 30-yard belly scraper.

**Desiccation cracks formed on basin bottom from drying the clogging layer.**

Ripping the basin bottom using the spring-toothed harrow.

CAP water does not carry a heavy sediment load. The fine-grained clogging material is primarily diatoms, blue-green algae, wind blown dust and unicellular green algae. The use of chemicals to control the algae is avoided to maintain the chemical quality of the recharged water. In 2003, CAP operators scraped the top 6 inches of material from the basin floors followed in January 2004 by ripping basins to rejuvenate declining infiltration rates.

Algae growth in the basins at AVRP

The control of weeds is important at AVRP due to the proximity of the Marana Northwest Regional Airport to reduce habitat for birds. Tamarisk is especially troublesome because chemical control is not effective. In the past, the chemical Rodeo was applied using truck-mounted sprayers, but recently goats have been brought in as a better method to control Tamarisk and other weeds.

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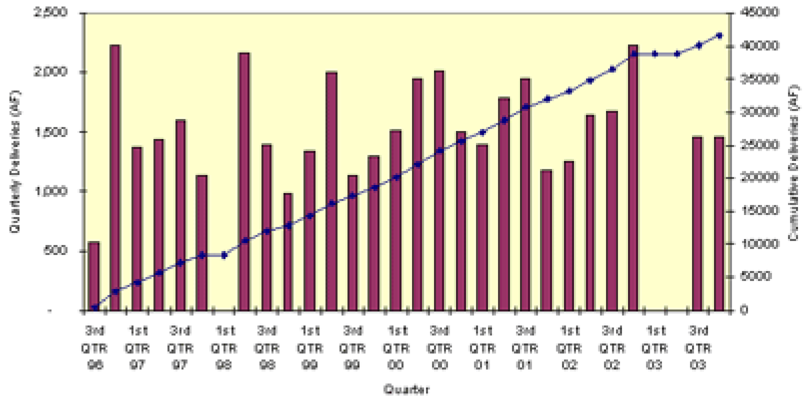
## WATER DELIVERIES

Water deliveries are tabulated daily for each basin and added up for the month. Evaporation losses are calculated using the 1970 Cooley method that calculates a maximum daily evaporation dependent on the time of year and the number of wetted acres for that day. Average evaporation rate losses are less than 1% of the stored volume. The deliveries are reported to the ADWR each month and are used by CAP to bill the individual customers storing water at the project.

In 2003, 2,907 acre-feet of water were delivered to the project. During the last 5 months of the year, the highest monthly delivery to the project was 856 acre-feet in October 2002, with the average being 650 to 750 acre-feet monthly. Through the end of 2003, 42,103 acre-feet has been stored at AVRP.

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CAP CENTRAL ARIZONA PROJECT

# Pima Mine Road Recharge Project





## INTRODUCTION

The Pima Mine Road Recharge Project (PMRRP) is a direct recharge project located in Pima County, approximately 15 miles south of Tucson, Arizona. The Central Arizona Water Conservation District (CAWCD), in cooperation with the City of Tucson, developed the project.

The facility is located on the Santa Cruz River flood plain and the facility has two operational components: The original pilot facility, which consists of a 2-mile delivery pipeline and one 14-acre spreading basin, and an expanded facility consisting of 5,500 feet pipeline and three new spreading basins totaling 23 acres.

Pilot testing was conducted from March 1997 to March 1999, under two Pilot Underground Facility Storage permits issued by the Arizona Department of Water Resources (ADWR). The pilot project was intended to assess the long-term feasibility of operating a larger full-scale recharge project. During the pilot phase, 20,000 acre-feet (AF) of CAP water were recharged. Full-scale operations began on September 8, 2000 using the pilot basin while construction of the expansion project was underway. The project expansion was constructed between May and December 2001. The completed facility provides a maximum permitted annual recharge capacity of 30,000 AF. Full-scale operation of the expansion basins began December 2001.

**Project Facts**

- Hydrologic feasibility assessments conducted for Pilot Facility 1991 thru 1998
- Location: T16S, R14E, West ½ Section 30 and SW ¼ Section 19
- Construction of Pilot Facility: completed March 1998
- Completion of Pilot Testing Phase 1 (10,000 AF): April 1999
- Completion of Pilot Testing Phase 2 (10,000 AF): March 2000
- Hydrologic feasibility assessments conducted for Expansion Project: April 1999 thru December 1999
- Project Expansion Construction: March 2001 to December 2001
- Total Construction cost: $11 million
- Completion date: December 2001
- Volume Stored to date: 83,934 AF (Jan 04)

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## FACILITY COMPONENTS

### Pilot Facility

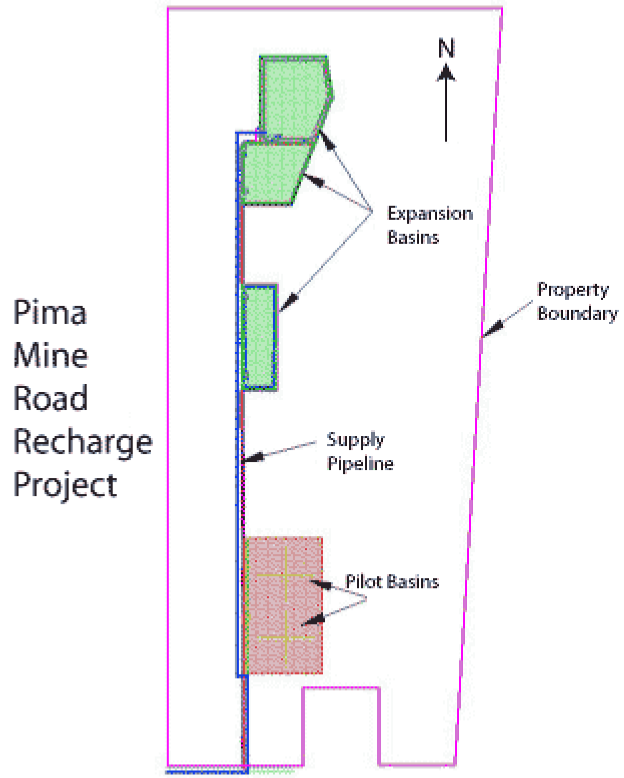
The Reach 6 portion of the CAP aqueduct provides water to the PMRRP facility. This section of the aqueduct consists of a 72-inch diameter pipeline from the Black Mountain Operating Reservoir (BMOR, (El. 2865) to the aqueduct terminus (El 2790). The BMOR/Reach 6 pipeline system creates substantial hydraulic head to the recharge facility.

**Placement of Delivery Pipeline Under the I-10 Freeway**

The pilot facility includes a 2-mile long, 36-inch diameter concrete coated, steel pipeline constructed from the CAP terminus to the pilot facility. The pipeline reduces to 24-inch diameter over the Santa Cruz River and upon entry into the recharge facility. Four turnouts constructed in subsurface concrete vaults divert water into each of the four basin quadrants. The delivery pipeline reduces to a 16-inch diameter line at the turnouts, then tees, where two 16-inch butterfly valve are used for basin delivery control. Pressure reducing valves were recently installed (July 2003) in each valve vault to reduce cavitation at the primary control valves.

**Construction of the Isolation Valve Fault and Flowmeter Vault**

The pilot facility has six acoustic flowmeters: one at the CAP turnout to the PMRRP pipeline, four at the pilot basin (one at each turnout), and one for the expansion basins located at the turnout from the pilot facility.




**General Site Layout**

The 14-acre pilot basin consists of two 7-acre sub-basins that are separated by a rip-rapped berm. Both sub-basins are excavated 13 feet below ground surface into floodplain deposits of the Santa Cruz River. Deep basin excavation was necessary to intersect deeper, coarse-grained alluvium for optimum infiltration rates.

**Rip-Rap Placement on Divider Berm**

Each sub-basin has 3-foot high perimeter and internal divider berms. Both are covered with rip-rap material to protect them from erosion by waves and surface water runoff.

**Basins Excavated and Ready for Recharge**

**Expanded Facility**

The Expanded Facility consists of a delivery pipeline and three new basins (Basins 1, 2 and 3) located north of the original pilot basin. The entire facility including the original pilot and new expansion cover nearly 1 mile in the north-south direction. The expansion basins were positioned where favorable coarse-grained deposits occur close to land surface. The basins were aligned linearly north to south, down slope of the pilot basin to comply with floodplain requirements.

**Operation of Three New Expansion Basins Down Slope from the Original Pilot Basin**

A 5,500 feet long, 36-inch diameter, steel delivery pipeline extends from the pilot basin north to the three new basins. Three 24-inch diameter turnouts equipped with pressure reducing valves and a 24-inch butterfly valve provide delivery control to each basin. One acoustic flow meter in the delivery pipeline measures combined flows to all three basins. An isolation valve at the turnout from the pilot facility allows maintenance on the expanded facility independent from recharge operations at the pilot facility.

Construction of Basin 3

Expansion Basins 1 through 3 were not excavated as deep as the pilot basin to reduce excavation costs. Basin 1 was excavated 6 feet, and Basins 2 and 3 were excavated 10 feet. The basin inverts are just above coarse-grained alluvium having high infiltration rates. The perimeter of each basin is lined with 6 feet of rip-rap to protect the basin edges from erosion by wave action and from surface runoff.

Construction of a Basin Turnout

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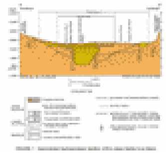
## HYDROLOGY

### Geologic Setting



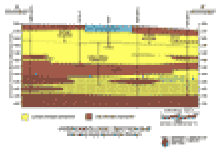
Hydrostratigraphic Cross-Section of the Pilot Basin Area (click image to enlarge)

The PMRRP site is located near the southern boundary of the Tucson Basin, which is a structural depression of the Basin and Range physiographic province. The basin covers approximately 1,000 square miles and trends north to northwest. The southern part of the Tucson Basin joins with the upper Santa Cruz basin, which extends south toward the international boundary with Mexico. Three Cenozoic stratigraphic units fill the basin. From oldest to youngest they are the Helmet Fanglomerate of Oligocene age, the Tinaja beds of Miocene and Pliocene age, and the Fort Lowell Formation of Pleistocene age. Above the Fort Lowell Formation are recent surficial deposits of Quaternary age. These are fluvial deposits related to the Santa Cruz River drainage system. The composite Cenozoic stratigraphic section of the Tucson basin is at least 20,000 feet thick. The adjacent figure shows the general structural configuration of the basin and sedimentary accumulations of the upper Tucson Basin near the project site.

Drilling conducted by CAWCD as part of project development indicates that the near surface deposits are unconsolidated alluvium associated with the modern floodplain. This recent alluvium consists primarily of fine-grained deposits of sandy silt and clay, and stratified silty sand, sandy silt and clay, but are underlain by a sequence of coarser-grained deposits consisting of sand, silty sand, gravelly sand, and gravel. The basins at the PMRRP facility were excavated to reach these lower deposits, which range from 10 to 20 feet below ground surface (bgs).

Beneath the recent alluvium is the Fort Lowell Formation, which consists of a sequence of unconsolidated to poorly consolidated, interbedded silt, sandy silt, sand and gravel. The Fort Lowell Formation is 300 to 400 feet thick throughout much of the basin, but ranges from 130 to 230 feet thick beneath the PMRRP site. The pre-recharge groundwater level was approximately 140 feet bgs in the Fort Lowell Formation, which comprises the shallow portion of the principal aquifer for the area.

### Hydrologic Setting



**Generalized Hydrogeologic Setting of the upper Tucson Basin (click image to enlarge)**

The sedimentary sequence within the main portion of the Tucson Basin has been subdivided into four hydrogeologic units based on lithology and groundwater flow characteristics. From ground surface, they are: recent alluvium, Fort Lowell Formation, Tinaja Beds and Helmet Fanglomerate. The regional aquifer in the area is comprised of the Fort Lowell Formation and Tinaja Beds.

The unsaturated hydraulic conductivity in the lower recent alluvium as determined by short-term infiltration tests ranged from 25 to 41 feet per day, but actual long-term infiltration rates determined from pilot basin operation range from 3.0 to 6.0 feet per day.

Groundwater in the project vicinity occurs under unconfined conditions within the coarse-grained portion of the Fort Lowell Formation. The pre-recharge depth to groundwater ranged from 140 to 145 feet bgs. On a regional scale, groundwater generally flows north to south parallel to the surface flow of the Santa Cruz River; however, a large cone of depression caused by pumping by a nearby copper mine is immediately upgradient, southwest of the project.

Aquifer tests conducted for the project indicate that the transmissivity of the upper Fort Lowell Formation range from approximately 11,000 to 84,000 gallons per day per foot (gpd/ft), and hydraulic conductivity values range from 160 gpd/ft (23 feet per day) to about 1,680 gpd/ft (225 feet per day). The lower values are associated with interbedded fine-grained units within the formation.

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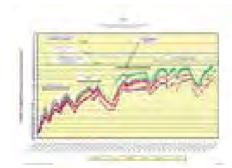
### MONITORING AND REPORTING



**Groundwater Level Hydrograph for the Pilot Basin Area (click to enlarge image)**

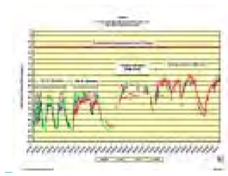
Hydrologic monitoring at the PMRRP facility consists of depth-to-water measurements at groundwater monitoring sites and water level depth measurements at the four recharge basins. The groundwater monitoring is conducted to assess hydrologic responses from the recharge operations and to assess water quality transformations over time. The monitoring is conducted in accordance with the project's monitoring plan that has been approved by the Arizona Department of Water Resources (ADWR) and the Arizona Department of Water Quality (ADEQ). A total of 52 monitoring sites are used to monitor vadose zone (unsaturated zone) and regional aquifer water levels. Of these, six monitor wells were specifically constructed to obtain groundwater samples to assess water quality transformations over time.

Daily monitoring of the four recharge basins is conducted to ensure that safe and effective ponding depths are maintained. Typically, the pilot basins are operated with ponding depths up to 2 feet, and the expansion basins are operated with ponding depths up to 4 feet. Ideally, ponding depths are maintained 2.5 feet or lower.

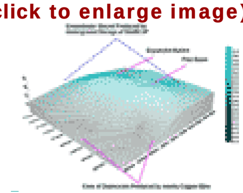
Groundwater level monitoring is conducted at various monitoring sites on a weekly to quarterly schedule depending on location relative to nearby sensitive land or water users. The monitoring is conducted to ensure that water depths do not rise too close to land surface. Prior to recharge, the depth to the ambient regional aquifer was 140 to 145 feet bgs. In response to recharge, a large groundwater mound has developed with onsite groundwater depths currently ranging from 56 to 64 feet bgs. Onsite perched water in the vadose zone sporadically occurs approximately 40 feet bgs.

Quarterly sampling is performed at six monitor wells to monitor water quality and to assess transformations resulting from recharge. Samples are tested for organochlorine pesticides, chlorinated herbicides, 11 trace metals, general minerals, and total coliform bacteria. To date, 22 groundwater sampling events have been performed with no indications of adverse water quality impacts.

Monitoring conducted for regulatory compliance is submitted in quarterly and annual monitoring reports to ADWR and ADEQ.



**Perched Water Response in Vadose Zone Piezometers (click to enlarge image)**



**3D Perspective of Groundwater Mound in January 2004 after 84,000 AF Recharged (click to enlarge image)**

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## OPERATIONS

Recharge operations were conducted at the pilot basin from March 1997 to March 1999 to assess the feasibility of operating a long-term, full-scale recharge project. During this time, 20,000 acre-feet (AF) of CAP water was stored using the single 14-acre pilot basin.

Full-scale operations began in September 2000 using only the pilot basin since the expanded facility was under construction. Recharge at the three project expansion basins began in December 2001.

Recharge operations at the pilot facility have consisted of either sub-basin rotations, or continuous recharge using both sub-basins depending on delivery constrains, infiltration rates and planned future outages. Rotating between the two sub-basins has allowed relative continuous operations with minimum infiltration loss. The rotation duration has ranged from one week to several months depending on infiltration rates. Both sub-basins are used when maximum recharge volumes are needed prior to a planned delivery outage or schedule basin maintenance.

Lower infiltration rates at the expansion basins requires continuous operations to meet management recharge goals; thus no basin rotations or wet/dry cycling is conducted. Typically, the basins are dry during summer months when water availability becomes limited due to high agriculture demand of CAP water.

After dry cycling or following basin maintenance, several weeks to months of operation is needed before basin ponding occurs sufficiently for falling-head infiltration testing. Infiltration rates at the pilot basin typically range from 1.9 to 5.8 feet/day, but are much higher initially after maintenance is conducted.

The expansion basins were not excavated as deep as the pilot basin and therefore infiltration rates are substantially lower. Infiltration rates range from 0.7 to 4.2 feet/day. Planned basin scraping late in 2004 should substantially improve the infiltration rates.

Recharge Operations at the Pilot Facility in March 1998

Goats Grazing on Tumbleweeds at Expansion Basins

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## MAINTENANCE

Maintenance is conducted during the course of routine operations. Typically basin scraping and ripping are performed to rejuvenate infiltration rates after wet/dry cycling become ineffective. Wet/dry cycling rotation of the two sub-basins is commonly used to rejuvenate infiltration at the pilot facility. For the first two years of operation, disking was performed every 6 to 9 months to loosen the upper soil layer. Due to the heavy reliance on this basin for recharge, a hard surface crust developed after two years of operation that required removal by scraping.

Deep basin ripping was performed shortly after construction of the expansion basins to reduce the compaction effects produced by heavy equipment. Annual basin scraping, followed by ripping to ensure maximum infiltration rates are maintained, is performed on each basin.

**View of Pilot Basin After 40,000 AF Recharged. Notice Hard Encrusted Surface Layer that Reduces Infiltration Rates.**

The PMMRP delivery system is under about 70 pounds per square inch (psi) pressure because of the elevation drop from the Black Mountain Operating Reservoir (BMOR) to the recharge project. The high pressure has caused cavitation damage at the control valves at the pilot and expansion facilities. Control valve replacement became routine from the ongoing cavitation problem. To mitigate the damage caused by cavitation, five 16-inch Pressure Reducing Valves (PRV) were installed in July 2003. Two were installed at the pilot facility and three were installed at the expansion basins. These valves have been very successful at controlling the cavitation and since their installation, no control valves have required replacement.

**In December 2001, Basin Scraping was**

In October 2003, CAWCD used goats at the PMRRP for the first time for weed removal. Approximately 430 goats were used over a 10 day period. An analysis of the effectiveness indicates that the goats were very effective in removing vegetation in the basins, but less effective in removing mature tumble weeds on the basin perimeters. In general, the weed eradication using goats is more cost effective than chemical herbicides, at about 50% of the cost. Additionally, recharge can be conducted while goats are being used, eliminating the drying time prior to, during, and after spraying of chemicals. The goats are planned to be used twice a year in the spring and fall before the tumble weeds mature.

**Conducted for the First Time at the Pilot Basin to Remove the Hard Crust Layer.**

**Maintenance Crew Fine Tunes PRV Valves That Were Installed in July 2003**

**Pilot Basin Clogged with Weeds. Notice Goats Canvassing the Distant Perimeter Area**

**Goats Starting a Hard Days Work in the Expansion Facility**

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## WATER DELIVERIES

Water deliveries are scheduled by the Water Planning Department, in coordination with the CAP Water Operations Department, to meet customer recharge delivery orders. A Water Storage Permit, issued from the Arizona Department of Water Resources (ADWR), and a Water Storage Agreement with CAWCD are necessary for any water user/supplier to store at the facility.

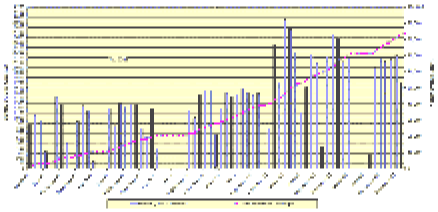
**Recharge Operations at the Pilot Basin**

Water deliveries are quantified monthly using flowmeters at the facility and are reported in acre-ft (AF). One AF is about 326,000 gallons. For the PMRRP facility, several acoustic flowmeters are used to measure flows at various points in the system. The CAP terminus flowmeter records flows entering the entire recharge facility. Four flowmeters record flows at each turnout at the pilot basin, and one flowmeter measures flows from the pilot facility turnout to the three expansion basins.

Losses are subtracted from the daily delivery volumes to determine the net recharge. At the PMRRP facility, losses consist primarily of evaporation, which is determined using the 1970 Cooley Method. Typical evaporation losses are approximately 0.5%.

The maximum monthly net recharge of 2,957 AF occurred in March 2002 in response to startup of the newly constructed expansion basins. In general, the current monthly recharge volumes range from 2,000 to 2,500 AF.

As of January 2004, a total of 84,349.81 AF have been delivered to the project with 415.47 AF lost to evaporation resulting in a net delivery of 83,934.34 AF stored underground.



**Net Monthly and Accumulated Water Deliveries at the PMRRP (click image to enlarge)**

Typical Acoustic Flowmeter in Use at Pilot Facility

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CAP CENTRAL ARIZONA PROJECT

# Lower Santa Cruz Recharge Project





## INTRODUCTION

The Lower Santa Cruz Recharge Project (LSCRP) was developed in a partnership between Central Arizona Project and Pima County Department of Transportation and Flood Control District (Pima County). The facility was constructed in conjunction with a flood control levee along the Santa Cruz River, using State Demonstration funds. The project is located near the Marana Airport west of the Tangerine Road exit off I-10.

**LSCRP Basins Being Excavated During Construction**

Approximately 750,000 cubic yards of material was excavated from the LSCRP site and used to stabilize the bank of the Santa Cruz River to protect the Town of Marana from flooding. Following excavation of the material for the flood control district, CAP completed the recharge project by construction of the basins and the water delivery infrastructure.

The LSCRP was originally conceived as part of the Northwest Tucson AMA Replenishment Feasibility Study. The Northwest Replenishment Program began in 1994 as a cooperative effort among water resource entities in the northwest Tucson AMA to investigate recharge feasibility in the Lower Santa Cruz River and Canada del Oro Wash corridors.

The facility consists of three basins ranging from 7.4 to 11.0 acres for a total of approximately 30 acres of spreading basins. Water is delivered to the site via an open channel irrigation canal. The flow into the facility is measured utilizing a Parshall Flume.

Parshall Flume

Customers storing water at this facility include the Arizona Water Banking Authority, Central Arizona Groundwater Replenishment District, Metropolitan Domestic Water Improvement District, the Town of Marana, and Robson Communities, Inc.

**PROJECT FACTS**

- Permit Capacity: 50,000 AF/yr, 600,000 AF total storage
- Cost: Total cost: $3.9 million - Cost to CAP: $1.5 million
- Volume Stored Through April 2004: 121,476 AF
- Number of basins: 3 basins ranging from 7.4 to 11.0 acres for a total of 30 acres
- Location: T12S, R11E, Section 3 NE Corner
- Construction Completed: June 2000
- Delivery Capacity: 65 cfs

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**FACILITY COMPONENTS**

LSCRP consists of three basins ranging in size from 7.4 to 11.0 acres for a total of approximately 30 acres. The water is delivered to the project using three natural gas-powered canal side pumps that are capable of pumping up to 11,000 gallons per minute each (approximately 25 cfs). The water is pumped into an open canal and conveyed approximately 1 mile from the CAP canal before being diverted into the project by manually adjusting a slide gate in the canal.

**Delivery Canal at the Diversion to LSCRP**

The water that is diverted into the basins is measured at a single Parshall Flume. Flows into the individual basins are not measured. The water level in the flume is measured by a pressure transducer installed in a stilling well and recorded every 15 minutes. Also, pressure transducers are installed in each basin to measure change in the water levels to ensure the basins don't overfill.

**Stilling Well in the Basin With a Pressure Transducer Installed Inside (Basin 1)**

**Solar Powered Remote Data Acquisition Site**

All the information collected at the project is recorded at a central remote data acquisition system that is powered by solar energy. The information is relayed to the Twin Peaks Pumping Plant by radio telemetry and brought back to the CAP Headquarters through the CAP canal microwave network.

LSCRP and AVRP are within the Federal Aviation Authority's (FAA) 10,000-foot radius of the Marana Northwest Regional Airport and, therefore, require mitigation to protect the airplanes from bird strikes. LSCRP, the larger of the two projects, employs the Phoenix Wailer that generates random noises to scare off loafing birds.

**Solar Powered Phoenix Wailer**

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## HYDROLOGY

The surficial geology in the immediate vicinity of the project site consists of Quaternary Recent Alluvium and the Quaternary Fort Lowell Formation. Geologic outcrops in the general vicinity include the Tortolita Mountains (located 5 miles northeast) and the Tucson Mountains (located 3 miles southeast). The Tortolita Mountains consist primarily of Cretaceous and Tertiary igneous rocks, and the Tucson Mountains consist primarily of Cretaceous igneous rocks.

The site is located within the Avra Valley alluvial basin within the Basin and Range Physiographic Province of southern Arizona. The alluvial deposits comprising the basin are the eroded remnants of the surrounding mountain ranges. The primary basin-fill deposits consist of (from youngest to oldest): Recent Alluvium (Quaternary), Fort Lowell Formation (Quaternary), and Tinaja beds (Tertiary).

Recent Alluvium: The Recent Alluvium occurs from ground surface to depths ranging from 32 to 84 feet. The Recent Alluvium consists of an upper interval of mostly fine to medium-grained floodplain deposits (7.5 to 30 feet thick), an intermediate interval of medium-grained stream deposits (0 to 11 feet thick), and a lower interval of coarse-grained gravelly stream deposits (16 to 56 feet thick).

Fort Lowell Formation: The Fort Lowell Formation consists of unconsolidated to poorly consolidated clayey, sandy gravel and clayey, gravelly sand with inter-bedded fine-grained intervals (ranging from 3 to 24 feet thick). Throughout most of the basin, the Fort Lowell Formation is 300-400 feet thick but, in the vicinity of the project, the formation is 250 to 275 feet thick.

Tinaja beds: The Tinaja beds are the principal water-bearing strata in the area. The beds are differentiated into three units: upper, middle, and lower. The upper Tinaja beds consist of unconsolidated to poorly cemented gravel to clayey silt; but in the uppermost part, the grain size is coarse and similar to the overlying Fort Lowell Formation. The middle Tinaja beds consist primarily of moderately cemented gypsiferous and anhydritic clayey silt and mudstone. The lower Tinaja beds consist of moderately to firmly cemented gravel and conglomerate to clayey silt and mudstone. The overall thickness of the Tinaja beds is estimated to exceed 1,500 feet.

The project is adjacent to the Santa Cruz River. Groundwater flows to the northeast paralleling the river. Prior to beginning operations groundwater was over 280 feet below ground level. Currently depth to water is approximately 190 feet.

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## MONITORING AND REPORTING

The USF permit issued by the ADWR requires that each project operator monitor responses from the recharge operations on the regional water level and water quality. The data must be submitted in the form of annual data reports. The LSCRP and AVRP are within one-quarter mile of each other and share the same monitoring network; therefore, in 2002 ADWR agreed that the two projects could be combined for reporting purposes.

**Aerial View of LSCRP (background) and AVRP (foreground)**

The monitoring network for both projects includes seven piezometers at each site for a total of 14 piezometers, 1 on-site monitor well at each site, and seven off-site monitor wells. Also, the water levels in each basin are monitored to ensure the basins do not overfill.

CAP staff collects water levels on a monthly basis with an electric sounder. The two on-site wells are equipped with continuous water level data loggers. The monitor wells, except for the Tangerine Landfill monitor wells, have an alert level that the mounding groundwater must be deeper than 20 feet below ground level. The Tangerine Landfill wells have alert levels set at 105 feet below ground level to protect the invert of the landfill from being saturated.

**Piezometer PZ-3**
**Located Between Basin 1 and Basin 2**

Water quality samples are collected and analyzed for the constituents listed in the USF Permit from four monitor wells. The alert levels are set as the NAWQS level for each constituent. Measured water quality components include inorganic and organic constituents, including pesticides and herbicides.

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## OPERATIONS

LSCRP began operations in June 2000 and consists of three basins totaling approximately 30 acres of recharge basins. CAP entered into a Water Transportation Agreement with BKW Farms, Inc. (BKW) to wheel water through BKW's irrigation canal system to the recharge facility. The water is measured at the CAP canal turnout with an acoustic flow meter and with a Parshall flume where the water is diverted into the recharge facility.

**BKW Farms Delivery Canal
to the Project**

The infiltration rate at LSCRP has been exceptional, exceeding 7 feet per day. Only two of the basins are needed at one time to store deliveries of over 60 cfs allowing the third basin to be in a drying cycle. Basins are rotated approximately every three weeks to minimize algae growth. The basins were in operation for over 2 ½ years before any mechanical maintenance was needed.

The facility was originally permitted for 30,000 AF/YR but, due to the high infiltration rates, the project had to be shut down in 2001 and 2002 because the maximum annual storage volume allowed under the permit had been reached. In 2003, CAP filed a permit modification with Arizona Department of Water Resources to increase the annual amount to 50,000 AF/YR. The modification was approved in 2003 and over 31,000 AF were stored at the project in 2003.

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## MAINTENANCE

Operations began in 2000 with over 60 cfs being delivered to the site. Through 2003, infiltration rates of over 7 feet per day have minimized algae growth and have allowed the maintenance to consist of only rotating basins.

**High Infiltration Rates Have Allowed Basin Rotation
to be an Effective Tool for Controlling Algae**

Towards the end of 2003, the infiltration rate began to drop and the basins were dried up for maintenance. The basin floor consists of cobbles and boulders and the spring-toothed harrow would not be effective; therefore, the basins were ripped using a D-9 dozer.

The remote data acquisition system and the bird deterrent system require routine maintenance. The units are installed near recharge basins and are subject to damage by lightening strikes, vandalism, and heat. Also, the units are operated off of 12-volt batteries that are recharged from solar panels and need to be replaced annually.

**Solar Powered Remote Data Acquisition Station**

The project is occasionally shut down because of high customer demands, planned maintenance on the pumping plants, or emergencies due to storm damage. The ideal time to perform all maintenance activities is during these forced outages. In June and July 2004, LSCRP is scheduled to be dry due to high customer demand and, during that time frame, the basins are scheduled to be scraped and ripped.

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## WATER DELIVERIES

Water deliveries are tabulated daily for each basin and totaled each month. Evaporation losses are calculated using the 1970 Cooley Method that calculates a maximum daily evaporation dependent on the time of year and the number of wetted acres for that day. Average evaporation losses are less than 1% of the stored volume. The deliveries are reported to the ADWR each month and are used by CAP to bill the individual customers storing water at the project.

Through the end of 2003, 108,462 AF has been stored at the LSCRP. In 2003, 31,909 acre-feet of water were delivered to the project. The highest monthly total delivered to the project since operations began was 3,977 AF in March 2003. In 2003, due to high customer demand, the project was dry for May, June and most of July.

In 2003, the ADWR USF permit was modified to increase the annual storage volume from 30,000 acre-feet per year to 50,000 AF per year and with planned modifications to the delivery canal by BKW Farms. It is anticipated that the average annual storage volume will increase to 40,000 to 50,000 AF per year.

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CAP
CENTRAL ARIZONA PROJECT

# Agua Fria Recharge Project





## INTRODUCTION

The Agua Fria Recharge Project (AFRP) is a direct recharge project located near the City of Peoria in Maricopa County. It is located approximately 4 miles downstream of New Waddell Dam (Lake Pleasant). The Central Arizona Water Conservation District (CAWCD) developed the project. In 2003 the City of Peoria purchased AFRP storage capacity to support water resources management goals by providing recharge for future population growth.

The facility consists of two operational components: a managed facility consisting of a four mile river section used for recharge and conveyance of surface water downstream, and a constructed facility consisting of a headworks structure to capture surface flow in the river and a conveyance canal to route water downstream to 100 acres of spreading basins.

Together, the managed and constructed facilities provide a total permitted recharge capacity of 100,000 acre feet per year. It is the only recharge project in Arizona to combine streambed recharge and infiltration basins at a single facility. The project operates under two Underground Storage Facility (USF) permits, one for each facility, issued by the Arizona Department of Water Resources (ADWR).


**Aerial View Showing Project Layout**

Managed recharge activities began in September 2001, while construction of the recharge basins and associated facilities continued. After completion of the constructed facility in May 2002, both the managed and constructed facilities commenced operation.

Recharge Operations at Constructed Facility

**Project Facts**

- Hydrologic feasibility assessments and permitting for full-scale facility: 1997 to 1998
- Construction of basin facility: April 2001 to May 2002
- Construction cost: $10.5 million
- Completion date: May 2002.
- Location: T4N, R1E, Section 6 East ½ (basins only)

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## FACILITY COMPONENTS

**Managed Facility**

CAP water is delivered into the low flow channel of the Agua Fria River (managed facility) via a blowoff structure in the Agua Fria Siphon. The inflows are measured using an acoustic flowmeter in the blowoff structure. CAWCD purchased land in the streambed and acquired flowage easements from various state and private landowners to allow use of the river for recharge and conveyance.

**Constructed Facility**

The constructed facility consists of an earthen dam (headworks structure) to capture surface flows from the river. The water is then conveyed to the spreading basins through a 4,000 feet long, trapezoidal, concrete-lined canal. A broad-crested weir is used to measure flow entering the recharge basins. The constructed facility consists of 7 spreading basins located in an embayment along the river's western terrace (Basins A - G). Water is distributed to each basin from Basin A, a sedimentation basin, which is connected to a distribution channel on the west side of the facility.


**Aerial View of Constructed Facility**

Concrete outlet structures are used to control deliveries to each basin and to provide grade control along the distribution channel as each basin is progressively lower in elevation southward. Basin A functions primarily as a desiltation basin. It is 14 feet deep with its outlet structure to the distribution channel at a depth of 9 feet. The remaining basins are 6 feet deep. The perimeter and basin divider berms are composed of native soils excavated from onsite, which have been mantled with riprap (cobble size material) to protect them from erosion.

**Broad-crested Weir above Recharge Basins**

**Blowoff Structure Releasing Water into the Agua Fria River**

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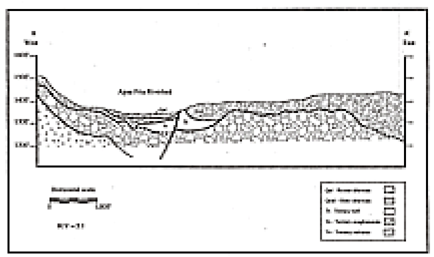
## HYDROLOGY

### Geologic Setting

The project is located on the northern margin of the West Salt River Valley (WSRV) Basin. The area has been affected by mid-Tertiary extension that formed regional detachment faults, and were later over-printed by Plio-Pleistocene Basin and Range faulting. The structural effect of the faulting was the tilting of Tertiary volcanic and sedimentary deposits and the deepening of the sedimentary basin southward.



**East-West Cross-Section near South End of Managed Facility**
**Click Image to Enlarge**

Drilling conducted as part of project development indicates that the surficial deposits are unconsolidated alluvium associated with the modern streambed. These deposits consist of moderately sorted sand, gravel and cobble channel deposits. Beneath the unconsolidated alluvial deposits are semi-consolidated gravels and conglomerates, which appear interstratified with volcanic tuffs, basalt, and andestic flows (Integrated Water Technologies, 1997). The conglomerate unit, which is weak to moderately cemented, may be greater than 800 feet thick in places based on logs of water wells in the project vicinity. Drilling conducted by CAWCD for the monitoring network indicates that the conglomerate unit is present beneath the recharge basins at a depth of approximately 150 feet. Transmissivities for this unit range from 1,000 to 75,000 gpd/ft (Dames and Moore, 1991).

**Hydrologic Setting**

The sedimentary sequence within the main portion of the WSRV Basin has been subdivided into three hydrogeologic units, based on lithology and groundwater flow characteristics (Corkhill, et al., 1993). These units include the Lower Alluvial Unit (LAU), Middle Alluvial Unit (MAU), and Upper Alluvial Unit (UAU). Based on the results of AFRP drilling activities, the MAU appears to be absent in the project area or substantially thinned suggesting that the three part hydrogeologic division of the WSRV Basin does not apply to the northern edge of the basin in the project vicinity.

**North-South Cross-Section Through Managed and Constructed Facilities**
**Click Image to Enlarge**

Groundwater in the project vicinity occurs under unconfined conditions within the coarse-grained alluvial aquifer. The pre-recharge depth to groundwater in the project vicinity ranged from 30 feet below ground surface (bgs) within the riverbed at the blowoff structure to over 300 feet bgs about a mile south of the recharge basin site. Beneath the recharge basins, the pre-recharge groundwater depth occurred from 200 to 230 feet bgs. On a regional scale, groundwater flows north to south through the project site toward the Deer Valley and Luke cones of depression, which resulted from excessive groundwater pumping in the Salt River Valley basin. Groundwater elevations deepen dramatically across the basin boundary fault system as the sedimentary sequence thickens to the south.

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## MONITORING AND REPORTING

Hydrologic monitoring at the AFRP consists of depth-to-water measurements at groundwater monitoring sites, water level depth measurements at the seven recharge basins, and water quality sampling of groundwater and source water. The groundwater monitoring is conducted to assess hydrologic responses from the recharge operations and to assess water quality transformations over time. The monitoring is conducted in accordance with the project's monitoring plan that has been approved by the Arizona Department of Water Resources (ADWR) and the Arizona Department of Environmental Quality (ADEQ).

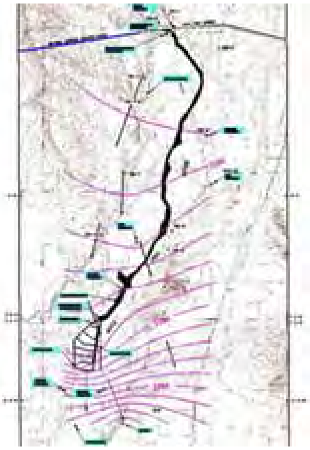
Daily monitoring of the seven basins is conducted to ensure that safe and effective ponding depths are maintained. Typically, the basins are operated with ponding depths up to 2 feet.

Six water level monitoring sites are used to monitor hydrologic responses at the managed facility and an additional six monitoring sites are used at the constructed facility. Groundwater level monitoring is conducted weekly to ensure that water depths do not rise too close to land surface. Groundwater depths range from about 20 feet below ground surface (bgs) in the Managed Facility to about 100 ft bgs just south of the basins.

Quarterly water quality sampling is performed at five monitor wells to monitor water quality and to assess transformations resulting from recharge. To date, eight groundwater sampling events have been performed with no indication of adverse water quality impacts.

Monitoring conducted for regulatory compliance is submitted in quarterly and annual monitoring reports to ADWR and ADEQ.

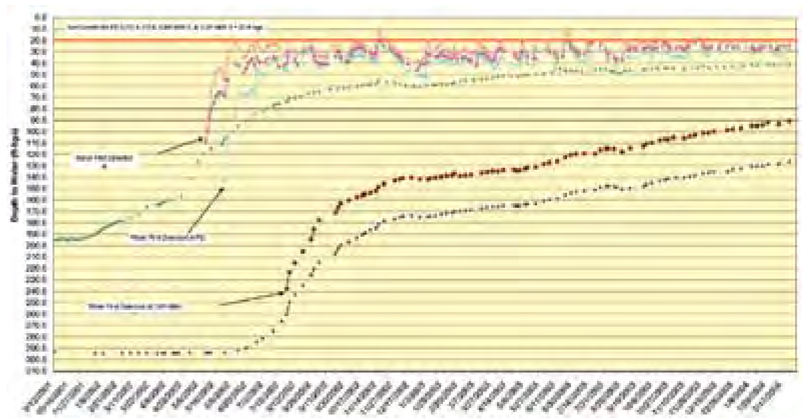
**Monitoring Network for Managed and Constructed Facilities**
**Click Image to Enlarge**



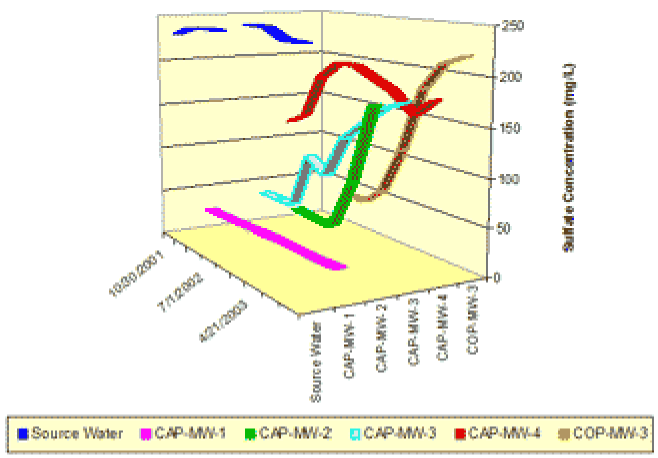
**January 2003 Groundwater Surface Contour Map**
**Click Image to Enlarge**

**Water Level Monitoring Being Conducted at Recharge Basins**

**Water Level Hydrograph for the Managed Facility**
**(click image to enlarge)**



**Water Level Hydrograph for the Constructed Facility**
**(click image to enlarge)**




**Sulfate Geochemistry Trend Graph Showing Temporal**
**Change to the CAP Water Type at Some Wells (e.g. CAP-MW-4)**
**Click on Image to Enlarge**

The geochemistry of CAP water is remarkably different from the natural occurring, ambient groundwater in the region. All groundwater contains minerals (salts) in dissolved concentrations based on the water's interaction with the geologic media. Recharging CAP water tends to shift the groundwater geochemistry towards the CAP water type. Because CAP water is lower in alkalinity and higher in sulfate, sodium, and other ions, changes to groundwater are primarily with these constituents, which can be used to track the arrival of CAP water to a particular location. Laboratory results from the last several sampling events indicate that the water chemistry at wells CAP-MW-2, CAP-MW-3 and CAP-MW-3 is rapidly transforming to the CAP water type as demonstrated by the sulfate geochemistry trend graph.

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## OPERATIONS

Managed recharge operations began in September 2001 with continuous releases from the blowoff structure. Spreading basin recharge began in April 2002 after several of the basins were constructed. Since that time, groundwater mounding beneath both facilities has required wet/dry cycling and strategic use of the recharge basins.

**Release into Agua Fria River via Blowoff Structure**

Basin ponding depths as well as depth-to-groundwater measurements are used to plan and schedule operations and determine the length of wet and dry cycles. Typically, wet cycles range from 3 to 7 days in duration and dry cycles range from 5 to 10 days in duration. When canal maintenance activities require an extended project shut down period, wetting cycles can be extended to 2 to 4 weeks. Occasionally, managed recharge is conducted exclusively to allow groundwater mounding beneath the basins to dissipate.

Infiltration rates for the managed facility (river section) have ranged from 2.7 to 4.3 ft/day with an average rate of 3.85 ft/day. Infiltration rates at the basins have ranged from 1.21 to 3.48 ft/day.

Water Captured from River at Headworks Structure for Delivery to Recharge Basins

**Typical Spreading Basin Wetting Cycle**

**Operator Adjusting Gate at Basin Inlet Structure**

Streambed Recharge in the Managed Facility

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## MAINTENANCE

Facility maintenance is conducted during routine operations to ensure optimum recharge efficiency. Typically, basin scraping and ripping are to rejuvenate infiltration rates after wet/dry cycling become ineffective. At the AFRP, deep basin ripping was performed after construction to reduce effects from compaction by heavy equipment. Since basin recharge began in April 2002, no basin maintenance has been required other than weed control.

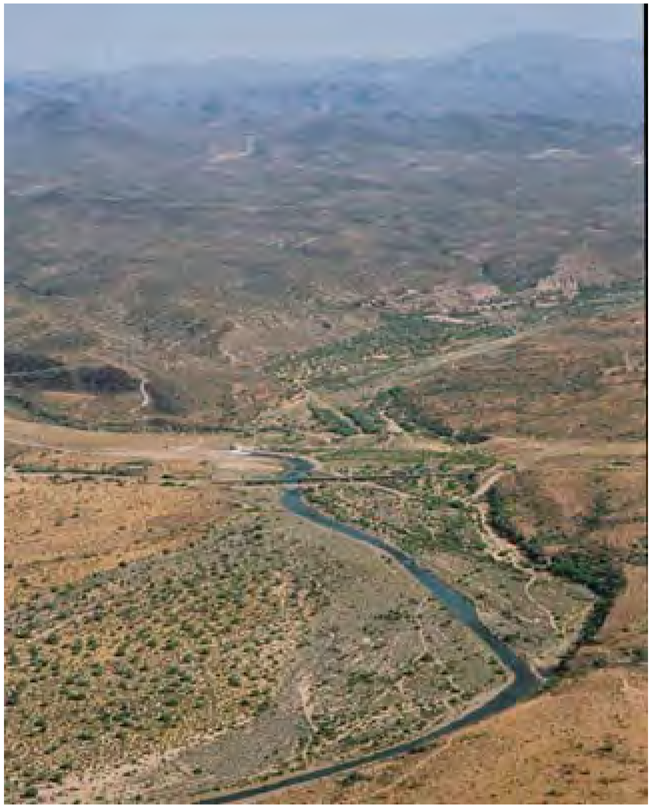
In October 2003, CAWCD used goats for weed removal as an alternative to application of costly herbicides. Approximately 430 goats were used over a 10 day period. The weed eradication using goats proved more cost effective compared to herbicides, at about 50% of the cost. Additionally, recharge can be conducted while goats are being used, eliminating the drying time prior to, during, and after spraying of chemicals. The goats are planned to be used twice a year in the spring and fall to control non-native, invasive weeds such as Russian Thistle (tumbleweeds) and Tamarisk (salt cedar).

**Invasive Salt Cedar Prior to Goats Arrival**

Goats Being Herded to Recharge Basins

Project is Operated Simultaneously with Weed Removal Activities

Basin after Weed Removal By Goats



**Maintenance is not Typically Required in the River Section**

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## WATER DELIVERIES

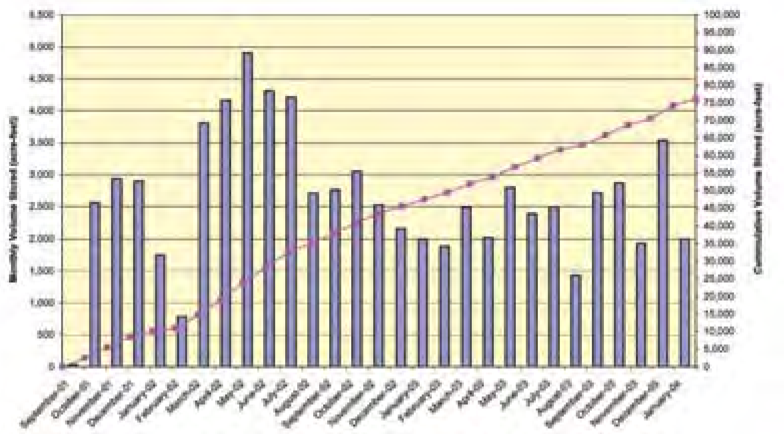
Water deliveries are scheduled through the CAP Control Center. A Water Storage Permit, issued from the Arizona Department of Water Resources (ADWR), and a Water Storage Agreement with CAWCD are necessary to store at the facility.

Acoustic Flowmeter at Blowoff Structure

Water deliveries are determined monthly using flowmeters at the facility and are reported in acre-feet (AF). One AF is about 326,000 gallons. For the AFRP, an acoustic flowmeter is used to measure deliveries from the blowoff structure to the entire facility. A broad-crested weir measures flow entering the spreading basins. Flow into the managed facility is the difference between the two measurements.

**Conveyance of Water to Basins**

Losses are subtracted from the daily delivery volumes to determine the net recharge. At the AFRP, losses consist primarily of evaporations, which is determined using the 1970 Cooley Method. Typical evaporation losses range from 0.5 to 1.0% of the volume delivered for recharge.




Cumulative and Monthly Net Recharge Volumes at the AFRP
(click image to enlarge)

The maximum monthly net recharge of 4,907 AF occurred during startup of the newly constructed recharge basins. In general, the current monthly recharge volumes range from 2,000 to 3,000 AF.

As of January 2004, a total of 76,603.5 AF have been delivered with 484.54 AF lost to evaporation resulting in a Net Delivery of 76,118.96 AF stored underground.

**Water Moving Down River at 225 cfs**

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CAP CENTRAL ARIZONA PROJECT

# Hieroglyphic Mountains Recharge Project





## INTRODUCTION

On January 2, 2003, the Central Arizona Project (CAP) began delivering water to the Hieroglyphic Mountains Recharge Project (HMRP). The direct recharge facility is located in the West Salt River Sub-basin of the Phoenix AMA, west of the intersection of 163rd Avenue and the CAP canal. The project has an annual permitted recharge capacity of 35,000 acre-feet (AF) per year. The project was developed and constructed using State Demonstration Project funds.

HMRP consists of three basins that cover approximately 38 acres along a one-mile stretch of the CAP right-of-way. The basins are divided into a total of seven cells with each cell capable of being operated individually. Water is diverted from the CAP canal to the project through a pump station. The pump station consists of four electric turbine pumps that can deliver up to 25 cubic feet per second (cfs) each. The flow is measured by an acoustic flow meter with an accuracy of +/- 0.5%.

Initial deliveries to the project, January 2, 2003 (Basin 2B)

Currently water is being stored for the Arizona Water Banking Authority and the Central Arizona Groundwater Replenishment District. The cities of Goodyear and Peoria have entered into water storage agreements at this facility for the future.

**Project Facts**

- Permit Capacity: 35,000 AF per year for 20 years
- Cost: $5.47 million
- Volume Stored Through April 2004: 30,208 AF
- Basins: Three basins, divided into 7 cells, totaling 38 acres
- Location: T5N, R2W, Section 23 and 24 South ½
- Project Operational: January 2003
- Operational Delivery Capacity: 50 cfs

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## FACILITY COMPONENTS

HMRP is composed of three basins, divided into seven individual cells. The cells range in size from 1.8 to 8.4 acres, for a total of approximately 38 acres of recharge basins. The water is pumped from the CAP canal using four electric turbine pumps rated at 25 cfs each. The deliveries average 40 to 45 cfs; therefore, only two pumps are used for deliveries with the other two ready as back-ups. The pumps are housed in individual sound reducing cabinets to protect the nearby neighbors.

Pump station at HMRP

The pumps are manifolded into a 42-inch pipeline with an acoustic flowmeter recording the flows every 15 minutes. Water is delivered to each basin through an upturned pipe with an apron of riprap to act as an energy dissipater. Flows to the individual cells are not measured. Pressure transducers installed in stilling wells record the water level in each cell. The normal operating level is less than 2 feet.

Inlet pipe with riprap and the basin stilling well
with the pressure transducer installed inside

Data is collected for the amount of water pumped, water levels in each basin, and pump status for each pump. Geomation Measurement and Control Systems provide remote monitoring and control for the facility. The data is relayed to CAP Headquarters through the existing fiber optic line where it is displayed in real time.

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## HYDROLOGY

HMRP is located southwest of the Hieroglyphic Mountains in the West Salt River Valley Sub-Basin of the Phoenix AMA. The mountains are composed of Tertiary and Cretacious intrusive and Proterozoic metamorphic rocks, with minor Tertiary volcanics. The project is located in the Basin and Range Physiographic province.

The surficial geology maps prepared by the Arizona Geological Survey classify the site as alluvial fan deposits of Holocene age. The surface deposits form a broad and gently sloping plain with a dendritic drainage pattern. HMRP is unique within the CAP recharge facilities in that it is not built near a stream channel; rather it is constructed on alluvial fan deposits near the margin of the Salt River Valley alluvial basin.

View of the alluvial fan with the Hieroglyphic Mountains in the background

The subsurface hydrogeology in the West Salt River Basin has been subdivided into three hydrogeologic units: Upper Alluvial Unit (UAU), Middle Alluvial Unit (MAU), and the Lower Alluvial Unit (LAU). The UAU consists of unconsolidated interbedded clay, sand, and gravel typical of basin fill material. Underneath HMRP, the UAU is approximately 265 feet thick and is dry. The MAU is predominately clay with interbedded sand and gravel lenses. Beneath the site, the MAU extends to a depth of approximately 510 feet. The LAU is semi-consolidated to consolidated sand and gravel and is the principal aquifer for the region. The groundwater is under semi-confined conditions with water levels at approximately 480 feet below ground level prior to beginning recharge operations.

Groundwater flow is from northeast to southwest in the vicinity of HMRP. Trenching and drilling at the site show interbedded sandy silt, silty sand, clayey gravel, and weakly cemented gravel zones. In general, the unsaturated zone beneath the basins (UAU and MAU) is dominated by silty sand and gravel.

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## MONITORING AND REPORTING

The underground storage facility permit issued by the ADWR requires that each project operator monitor responses from the recharge operations on the regional water table and potential perched conditions as well as water quality. The HMRP has ten piezometers and two monitor wells to measure the impacts of the recharge operations. In addition, each of the seven basin cells has a pressure transducer installed in a stilling well to measure water levels.

Basin stilling well with pressure transducer mounted
inside to measure water levels in the basin (Basin 2B)

The ADWR requires **weekly water level measurements** in the piezometers and monitor wells and quarterly water quality sampling from the two monitor wells. After 2 years of operation, the operator can petition the ADWR to reduce the monitoring to monthly for the water level measurements and semi-annual for the water quality sampling.

The nested piezometers are constructed to monitor potential mounding beneath the basins. During the exploration phase of the siting study, two relatively shallow 4 to 8-foot thick, fine-grained layers were encountered at depths of approximately 40 and 90 feet below ground level. The observed mounding follows a similar pattern seen at the other recharge projects: at start-up of a basin, the recharged water forms a mound above the fine-grained unit then dissipates as the fine-grained becomes saturated.

Alert levels are established in the ADWR USF permit issued for the project. Water levels in the wells cannot be less than 20 feet below ground level and the water quality analytes cannot exceed the ADEQ NAWQS standards. CAP monitors water quality both in the groundwater and source water. CAP monitors inorganic constituents as well as organic constituents such as herbicides and pesticides. Since operations have begun, there have been no exceedences of any of the established alert levels.

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## OPERATIONS

Deliveries began on January 2, 2003 with water being stored primarily for the AWBA and the CAGRD. In December 2003, the City of Goodyear obtained a Water Storage Permit from the ADWR and plans to store water at the facility in 2004.

Water levels are measured in each basin with depths typically held at 2 feet or less. As water levels rise, basin rotations are utilized to dry each basin and rejuvenate the infiltration rates. Initial infiltration rates in the individual cells ranged from 3.1 to 6.8 feet per day and have remained over 3 feet per day for the project has a whole. At the end of 2003, infiltration rates dropped to less than 2 feet per day due to clogging and, in January 2004, the project was dried and ripped. Since the ripping, infiltration rates are again over 3 feet per day.

Basin 2 with the northern cell wet and
the southern cell in a drying cycle

During normal operations, approximately 80% of the basin area is wetted with 20% in the drying mode. The basins are rotated approximately every two weeks to give the unused basins sufficient time to dry. Flows to the project average 40 to 45 cfs with two of the four pumps operating. The pumps are alternated monthly.

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## MAINTENANCE

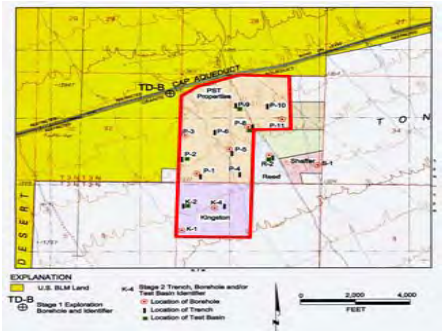
Maintenance is required to maintain good infiltration rates, ensure that the electrical and mechanical equipment operates properly, and to manage weed growth. Maintaining good infiltration rates is imperative with recharge projects and is accomplished through a combination of basin rotation and mechanical scraping and ripping. The physical attributes of the project, pumps, valves, remote data acquisition system, all require regular preventative maintenance (PM) to ensure reliable operations.

The basins are operated with approximately 80% of the basin area wet and 20% dry. By rotating the wet/dry cycle through the seven cells, algae growth is kept to a minimum. Since beginning operations in January 2003, only one mechanical ripping of the basins has been required to keep the infiltration rates over 3 feet per day.

HMRP basins with the northern basin in the wet cycle and the southern basin in the dry cycle

The pumping station has four electric turbine pumps that require regular PM's. The maintenance includes lubricating the pump shafts, inspecting the impellers, and monitoring the pump vibration. Also, the trash rack between the forebay and the canal requires regular cleaning. During periods of monsoons, tumbleweeds clog the intake to the pumps and require back flushing.

Electric pump at the HMRP turnout



TDRP Property
Click Image to Enlarge

**TDRP Facts**

- Hydrologic feasibility assessments conducted from 2000 – 2003
- Construction of TDRP: estimated start July 2004
- Ccompletion estimated November 2005
- Infiltration estimate of 2.5 acre-feet per acre
- Basin infiltration area = 206 acres
- 19 infiltration basins
- Largest basin = 14.1 acres
- Smallest basin = 6.6 acres
- Sloped basin bottoms to reduce excavation
- Gravity turnout with diversion capacity of 310 cfs
- Remote operation and monitoring capability
- Maximum annual storage capacity of 150,000 acre-feet per year
- Maximum storage after 20 years is 2,000,000 acre-feet
- Pipeline distribution system

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**FACILITY COMPONENTS**

The Hayden Rhodes Aqueduct, Reach 6 portion of the CAP aqueduct provides water to the TDRP facility. The facility is served by a gravity turnout that provides water to an 84-inch diameter pipeline. The inflow to the project is measured by an acoustic flowmeter. The distribution pipeline ranges in size from 84-inch diameter to 24-inch diameter pipe.

The distribution pipeline is approximately two miles long. The pipeline serves 19 infiltration basins. Inflow to each basin is controlled by eccentric plug valve. Each valve is motor operated and may be controlled remotely at CAWCD headquarters. Inflow to each basin is measured by an insertion flowmeter. Water levels in each basin are measured and monitored by pressure transducers.

Remote operation and monitoring is accomplished through a programmable logic controller (plc). The inputs from each basin (valve position, inflow, and water levels) and the acoustic flowmeter are sent to the plc. The plc then reports the information to CAWCD headquarters.

The project design includes sloped basin bottoms. The slope of each of the 19 basins follows the natural gradient of the site. A minimum of 3 feet is excavated during construction. A typical basin has up to 4 feet of depth in the down-gradient portion of the basin and up to 1 foot of depth in the up-gradient end of the basin. Each basin includes an overflow spillway to protect from overflows.

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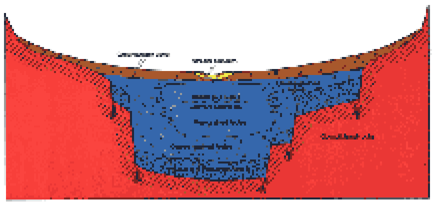
## HYDROLOGY

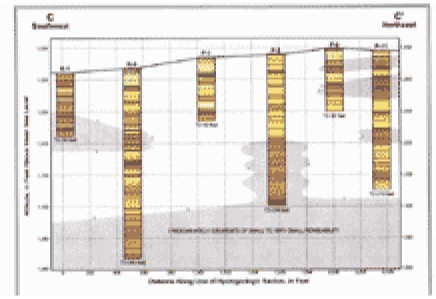


**Generalized Hydrogeologic Setting of the Lower Hassayampa Basin (click image to enlarge)**

### Geologic Setting

The TDRP site is located near the northwest boundary of the Lower Hassayampa Basin, which is a structural depression of the Basin and Range physiographic province. The basin generally trends northwest to southeast. The basin is thins to the southeast. The basin includes the Hassayampa River drainage and is bounded by the Gila Bend Mountains to the south and the Big Horn Mountains to the North. The basin terminates in the vicinity of Arlington at Gillespie Dam. Three informal Cenozoic stratigraphic units fill the basin. The coarse-grained material generally occurs adjacent to the basin margins. The sediments are generally finer-grained toward the center of the basin. From oldest to youngest they are the “lower basin fill”, the “upper basin fill”, and stream alluvium. These units are informally grouped into three hydrostratigraphic units, following the nomeclature used in the Salt River Basin: lower alluvium, middle alluvium, and upper alluvium. The composite Cenozoic stratigraphic section of the Lower Hassayampa Basin is at least 5,000 feet thick. The adjacent figure shows the general structural configuration of the basin and general stratigraphy of Lower Hassayampa near the TDRP project site.

Drilling conducted by CAWCD as part of project development indicates that the depth to groundwater at the site is approximately 490 below land surface. Groundwater flows generally from northwest to southwest at the site.The vadose zone consists of primarily of unconsolidated stratified silty sand, sandy silt and clay, coarser-grained deposits consisting of sand, silty sand, gravelly sand, and gravel.



**General Hydrostratigraphic Cross-Section of the TDRP Area (click image to enlarge)**

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CAP CENTRAL ARIZONA PROJECT

# Superstition Mountians Recharge Project

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## INTRODUCTION

Superstition Mountains Recharge Project (SMRP) is in the design and permitting phase of development. The project's goal is to provide 85,000 feet per acre of storage capacity in the East Salt River Valley (ESRV). The project is estimated to begin storage in 2006.

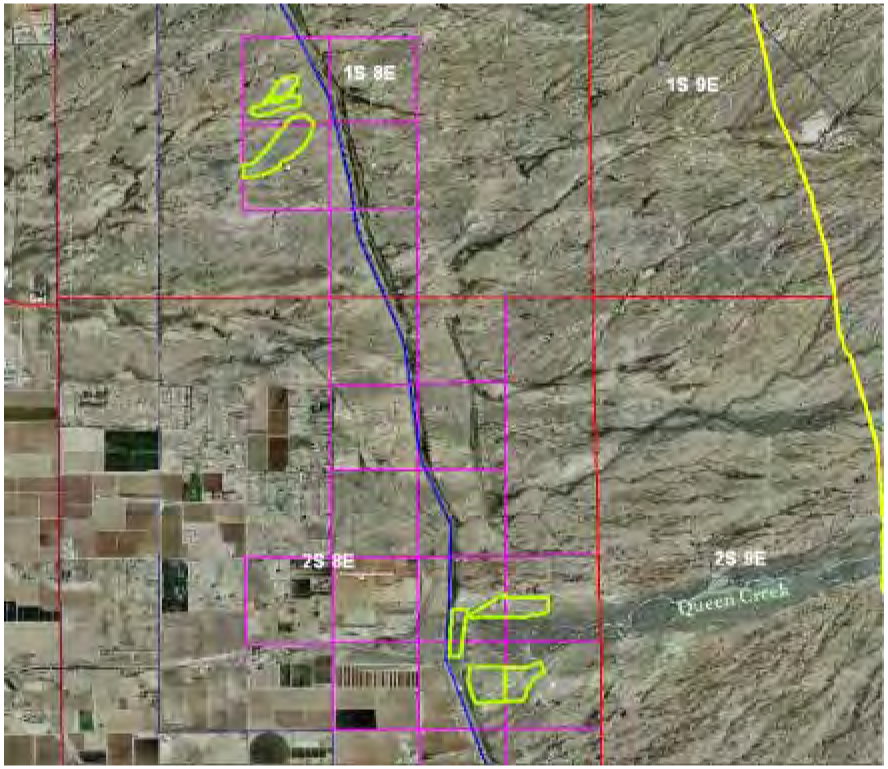
In 2002, CAP initiated a siting study for the SMRP. The goal of the study was to locate areas in the ESRV sub-basin of the Phoenix AMA suitable for a large-scale surface spreading recharge project. ESRV is an area of historic groundwater decline that has resulted in land subsidence and the formation of earth fissures.

The east valley continues to grow and the reliance on groundwater is becoming more critical. Developers are relying on the Central Arizona Groundwater Replenishment District (CAGRD) to meet their 100-year assured water supply. It is projected that the CAGRD will have a storage obligation of up to 85,000 AF per year in the ESRV. A large-scale recharge project will be required to meet the storage obligation.

**Earth fissure at the corner of Baseline and Meridian Road in the East Salt River Valley**

CAP contracted with GeoTrans to conduct a recharge feasibility study. The study was broken into two phases: Phase A involved collecting all available data, evaluating the data, developing a ranking criteria for all available sites, and choosing individual sites for further on-site investigations. Phase B involved on-site investigations including soil analysis, infiltration testing, and fatal flaw analysis.

The study area for the Phase A work was defined as east of the Roosevelt Water Conservation District Canal, south of the Salt River Project South Canal, north of the Phoenix active management area boundary, and 5 miles east of the CAP canal (approximately 410 square miles). The eastern boundary was set at 5 miles from the CAP canal because further east would be cost prohibitive to build a project.




**Six subregions selected for further on-site field investigation**

The Phase B investigation involved on-site soil and infiltration testing to determine if the sites were suitable for a recharge project.

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## SOIL TESTING:

The soil testing consisted of:

- Thirty backhoe trenches to a depth of 8 to 18 feet
- Eight boreholes to a depth of 99 feet using the sonic drilling method
- Three boreholes to 300-foot depth using the percussion hammer drilling method
- One borehole to 500-foot depth using the reverse-air rotary drilling method including sampling the ambient groundwater quality
- Submit representative samples of the fine and coarse-grain samples for laboratory grain size and plasticity analysis

The northern three subregions were rejected after digging eleven backhoe pits to depths of 7 to 10.5 feet. All eleven pits encountered silt to silty sand to a depth of 7 to 9 feet with backhoe bucket refusal due to strongly calcium cemented material. The pervasive presence of fine-grained material made the northern sites infeasible. No further investigations were completed in the northern parcels. All the effort was shifted to the three south subregions.


**The three southern subregions showing the backhoe trench locations**

The southern sites consist of a total of approximately 345 acres. Twenty backhoe trenches were dug throughout the three subregions. The results were positive with the top 0-6 feet of material consisting of a silt underlain by a coarse unconsolidated sandy gravel.

**Geologic Log of a Backhoe Pit in the Western Most Subregion**

The soil borings were concentrated on the subregions on the north and south side of the Queen Creek drainage. Eight borings were drilled to a depth of 99 feet,3 to 300 feet, and 1 to 500 feet.

**Geologic Cross Section Along the Southern Subregion**

The results were consistent between the two sites with coarse material interbedded with thin fine-grained stringers to a depth of approximately 310 feet where the middle fine-grained unit was encountered. Depth to water was approximately 450 feet and the water quality results did not indicate any significant concerns. The overall results of the soil investigation indicated the southern sites were favorable for a large-scale spreading basin recharge project.

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## INFILTRATION TESTING

The infiltration testing consisted of four infiltration basin tests and 10 cylinder infiltrometer tests conducted at locations of previous trench and borehole investigations. The tests were conducted in both the overlying silty layer and the underlying coarse-grained unit.

Two test basins were constructed at each of two of the trench locations for a total of four basins. At each location, one basin was placed in the silty unit about three feet below ground level and one was in the coarse-grained material about eight feet below ground level. Water was applied to each basin from a portable 7,000-gallon storage tank located at each trench site. The basins were filled to a depth of 1.5 feet, allowed to drop to a depth of 0.5 feet, then refilled. The time and exact drop in water level were recorded for each filling cycle. The process was repeated until the storage tank was empty.

Ten cylinder infiltrometer tests were conducted. Four of the tests were performed in the infiltration test basins prior to flooding the basin. The other six were performed in pits dug by a backhoe. Five of the tests were in the coarse-grained unit and one was in the silty unit. The method of testing used was a short term, single-ring infiltration test that is described in detail in Bouwer, et al (1999).

The results of the infiltration tests between the basin tests and the single-ring infiltrometer tests were fairly consistent. The infiltration rates for the basin tests in the coarse-grained unit were 4.3 and 7.4 feet per day while the single-ring tests in the same basins prior to flooding resulted in rates of 5.4 and 9.3 ft/day. The average rate for the single-ring for the 7 tests conducted in the coarse-grained unit was 4.9 ft/day. As expected, the testing in the silty unit above the coarse-grained unit resulted in lower results with the basin tests having calculated infiltration rates of 1.9 and 1.4 ft/day and the average of the single-ring tests being 2.2 ft/day.

The results of the infiltration tests indicated the site appears to be very favorable for a large-scale recharge project.

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## FUTURE WORK

Future work will include permitting, land access, design, and construction. The size of the project has yet to be determined but a range of up to 85,000 AF is being reviewed. Also, it is anticipated that the project will be built in two phases with the southern subregion being developed first.

The Permitting includes:

- ADWR Underground Storage Permit
- USCOE 404 Permit
- USBR Environmental Assessment
- Pinal County Floodplain Use Permit

Land access will include the US Bureau of Reclamation and the Arizona State Land Department. A detailed archeological and biological study will be required as part of the land access.

Unique design elements included in the project are: crossing the Sonokai flood control dike, pump intakes mounted on existing canal lining, strategies to minimize impacts to jurisdictional waters of the U.S. and a phase design.

Design and construction will be accomplished using outside consultants and contractors with CAP personnel providing oversight. The project is scheduled to begin construction in 2005 with operations starting in 2006.

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# Government Decision-Making

Rate-Setting Decisions

# Central Arizona Project

- Delivers Colorado River water to central and southern Arizona
- Customers
  - Municipal and Industrial (M&I)
  - Federal (primarily Indians)
  - Agriculture
  - Recharge


LAKE HAVASU
BILL WILLIAMS RIVER
MARK WILMER
BUCKSKIN MOUNTAINS
BOUSE HILLS
COLORADO RIVER
93
AGUA FRIA RIVER
NEW RIVER
VERDE RIVER
LAKE PLEASANT
WADDELL
60
17
HIEROGLYPHIC MOUNTAINS
HASSAYAMPA
AGUA FRIA
BURNT MOUNTAIN
LITTLE HARQUAHALA
TONOPAH DESERT
10
PHOENIX METRO AREA
THEODORE ROOSEVELT LAKE
SALT RIVER
SALT GILA
N
SUPERSTITION MOUNTAINS
GILA RIVER
SANTA CRUZ RIVER
8
BRADY
PICACHO
RED ROCK
MARICOPA COUNTY
PINAL COUNTY
PIMA COUNTY
LOWER SANTA CRUZ
AVRA VALLEY
TWIN PEAKS
SANDARIO
TUCSON
SNYDER HILL
BRAWLEY
BLACK MOUNTAIN
SAN XAVIER
PIMA MINE ROAD
PUMPING PLANT
SIPHON/PIPELINE
RECHARGE PROJECT
TUNNEL
DAM

# Management

- Popularly elected Board of Directors
- 15 Directors serve staggered six-year terms
  - 10 Maricopa County
  - 4 Pima County
  - 1 Pinal County
- Directors on ballot every two years

# CAP Rate-Setting Policy

- Recovery of costs
- Encourage full use of CAP's CO River apportionment
- Financial stability
- Price stability and predictability
- Operational efficiency
- Accountability
- Maximize economic benefit
- Legal Compliance

# Rates vs Expenses

- Several rate types within customer classes
- Electricity is CAP's largest expense
- CAP authorized to levy property taxes

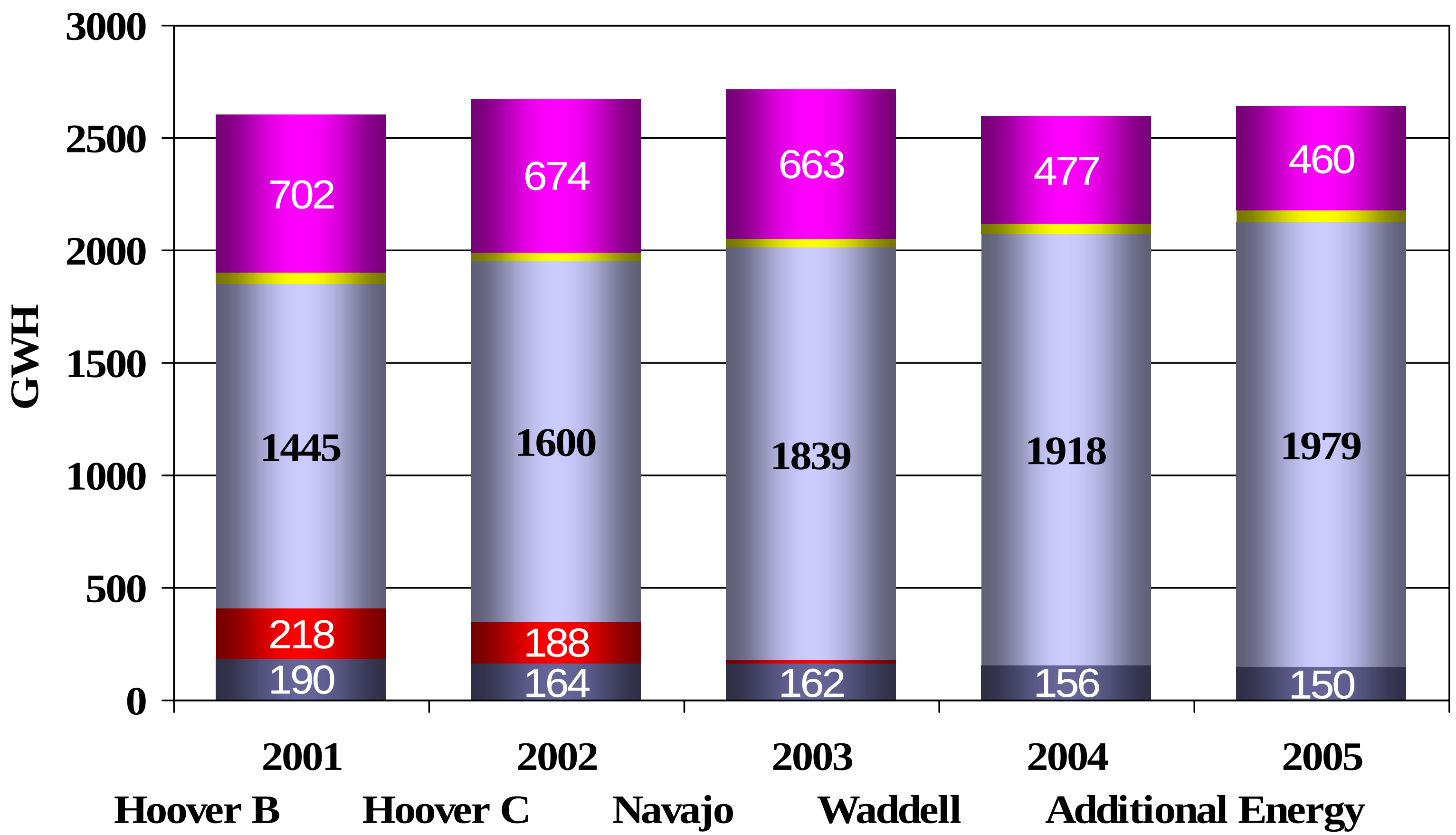
# 2005 CAP Rates ($/acre-foot)

| | |
|---|---|
| Municipal and industrial (M&I) and Federal | |
| - Fixed operations & maintenance (O&M) | 47 |
| - Pumping electricity | 32 |
| | 79 |
| M&I capital charge | 28 |

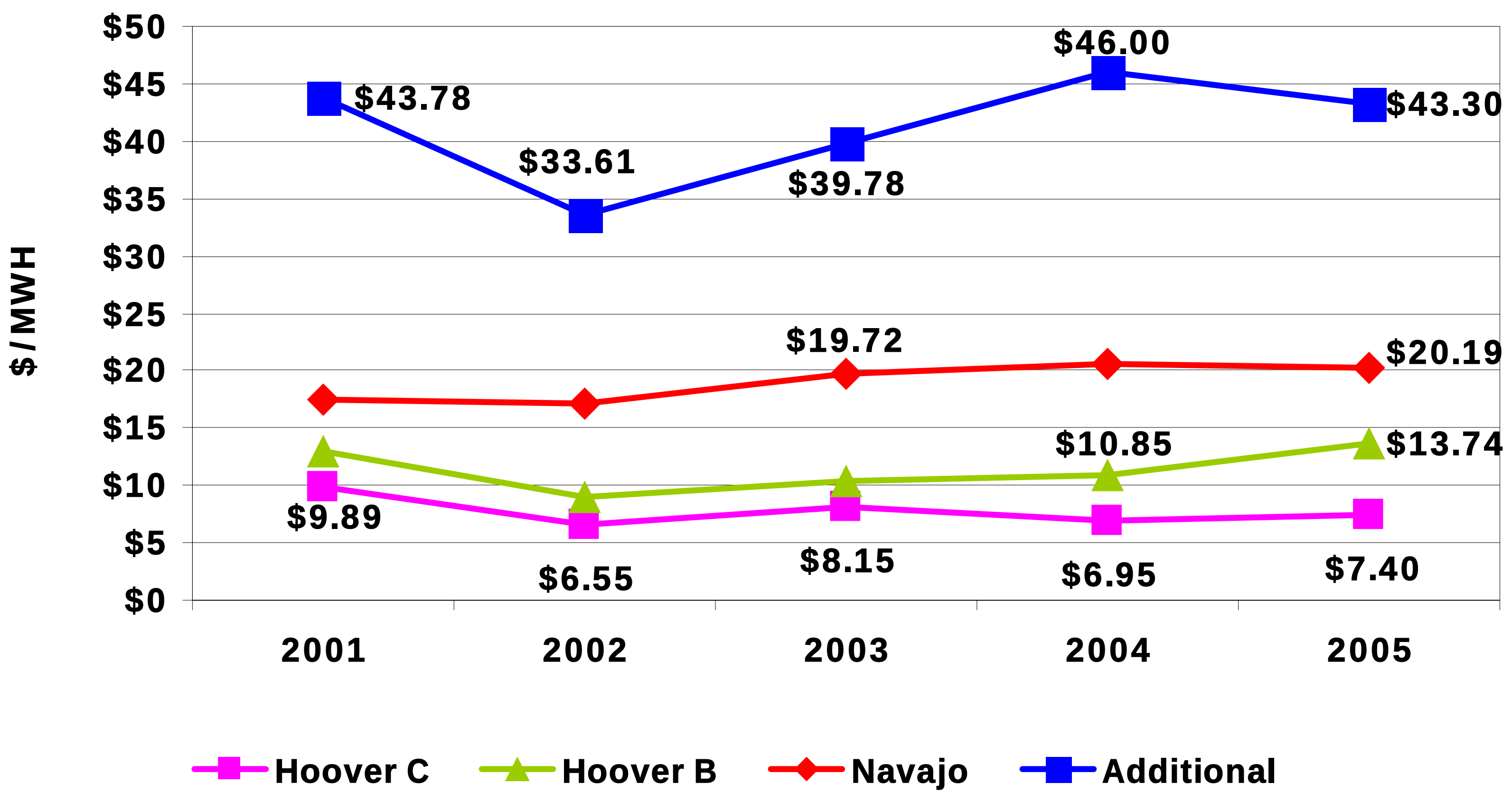
| | |
|---|---|
| Recharge | |
| - Fixed O&M | 11 |
| - Pumping electricity | 62 |
| | 73 |
| Agriculture pool | 32 |

| | |
|---|---|
| Interstate water banking | |
| - Fixed operations & maintenance (O&M) | 47 |
| - Pumping electricity | 58 |
| - Capital charge equivalency | 28 |
| - Property tax equivalency | 20 |
| | 153 |

# Pumping Energy



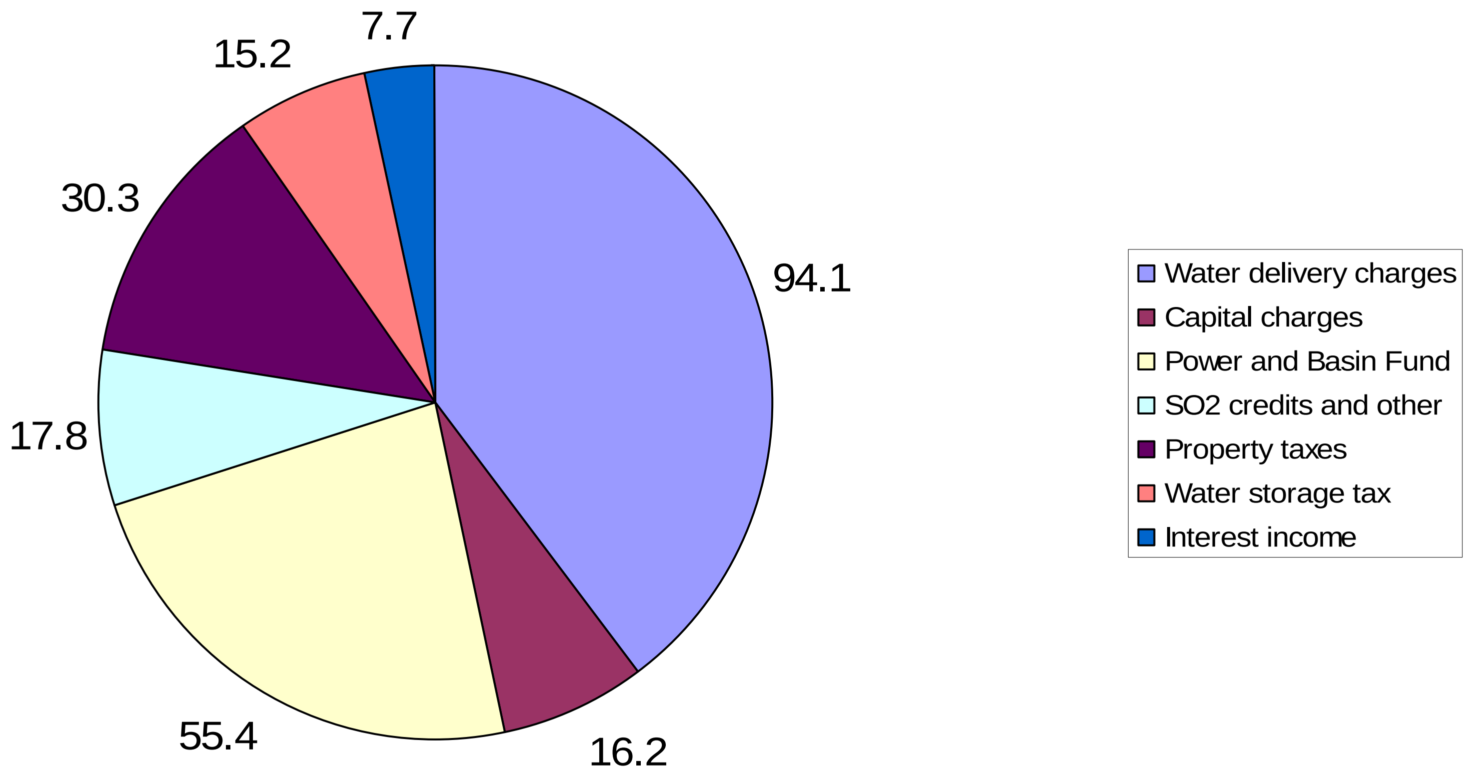
# Pumping Energy Costs
($/MWH)



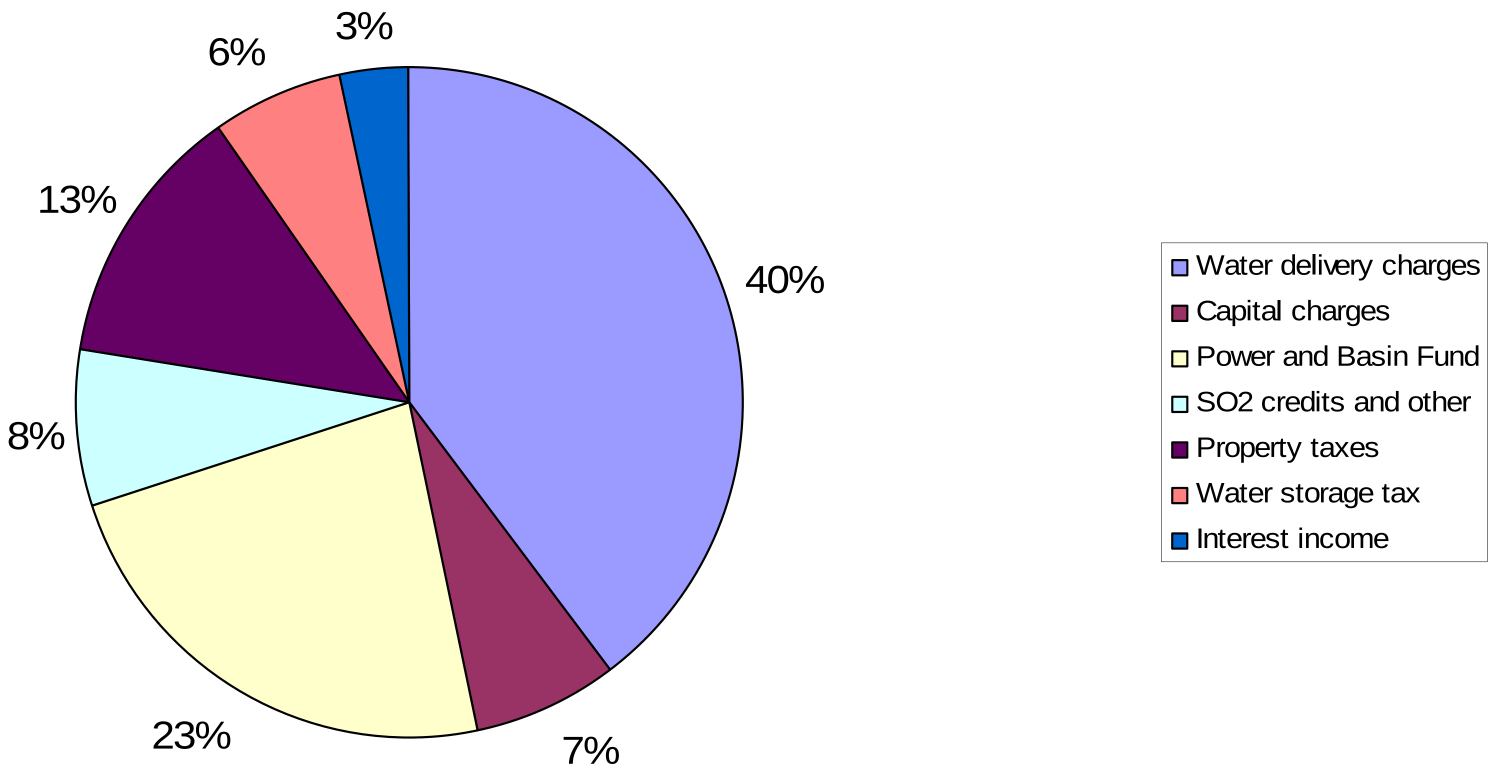
# Historical Ag Prices

| | 1990-1993 | 1995 | 1999 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|---|
| Subcontract | ~ 50 | n/a | n/a | n/a | n/a | n/a |
| Excess | ~ 60 | n/a | n/a | n/a | n/a | n/a |
| Pool 1 (200,000 a-f) | n/a | 27 | 32 | 34 | n/a | n/a |
| Pool 2 (200,000 a-f) | n/a | 17 | 22 | 24 | n/a | n/a |
| Pool 3 (<150,000 a-f) | n/a | 41 | 45 | 36 | n/a | n/a |
| Settlement Pool (400,00 a-f) | n/a | n/a | n/a | n/a | 28 | 32 |

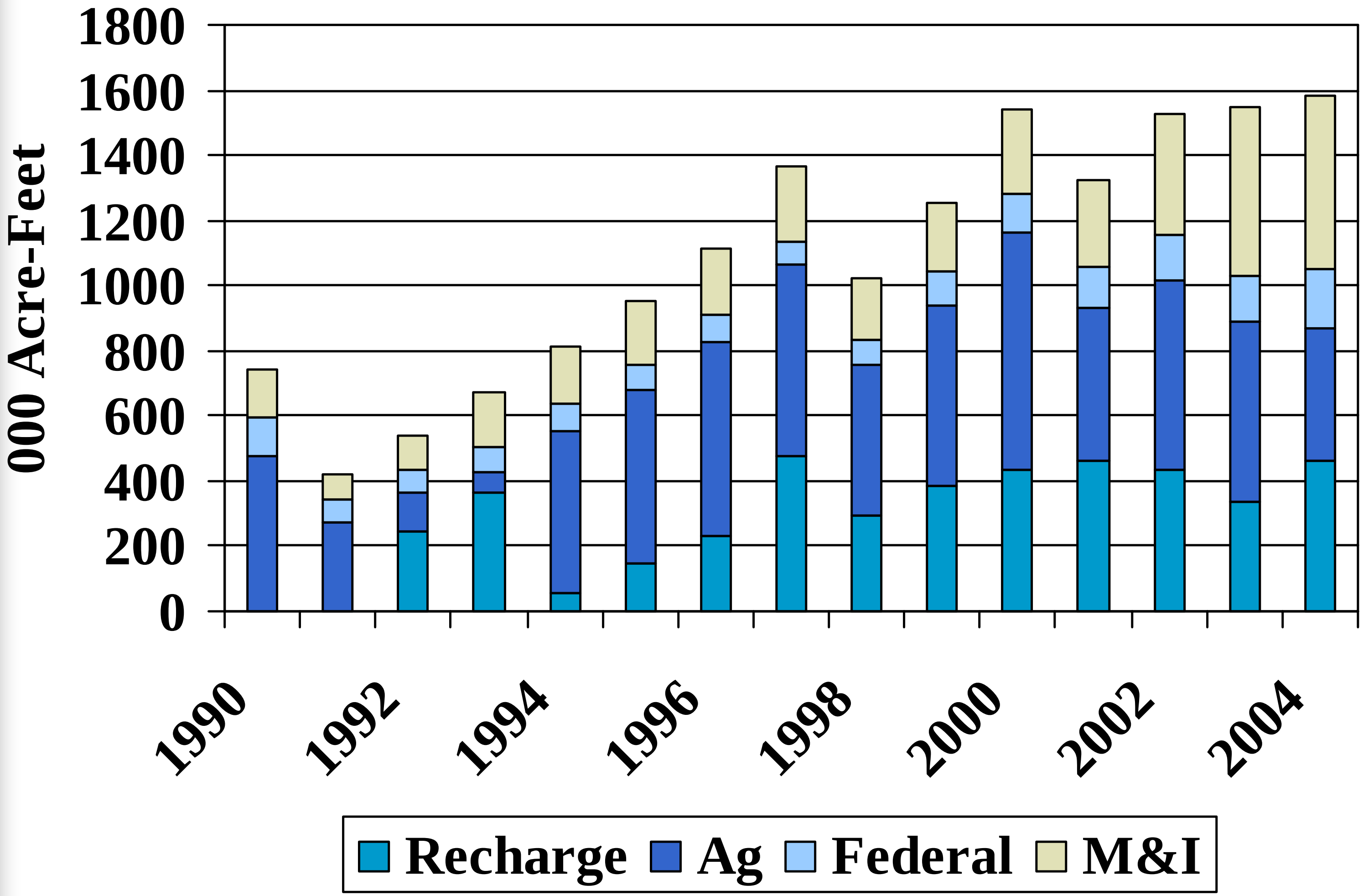
# 2005 CAP Revenues - $237 M



# 2005 CAP Revenues - $237 M



# Deliveries



000 Acre-Feet
1800
1600
1400
1200
1000
800
600
400
200
0
1990
1992
1994
1996
1998
2000
2002
2004
Recharge
Ag
Federal
M&I

# CAP Rates vs. Local Retail

- M&I delivery rate + capital charge = $107 acre foot
- $107 per acre foot = 0.03 cents per gallon
- Valley residential rates (15,000 gallons/month)
  - Range from 0.15 cents per gallon to 0.26 cents per gallon

# CAP Rates vs. Regional Retail

- Residential rates in the west range
  - Albuquerque = 0.10 cents per gallon (groundwater)
  - Los Angeles = 0.30 cents per gallon
- Costs of treatment, distribution and infrastructure add to the cost of raw water

# Rate-Setting Considerations

- Availability of other revenue sources (property taxes, interest income from investments, sales of sulphur dioxide credits, power sales)
- Reserve strategy (increase, decrease or maintain)
- Contractual (calculate federal price only in specified way)

# Rate-Setting Considerations

- Rate subsidies
  - To take all of CAP's apportionment
  - To make cost of CAP water competitive with groundwater for agriculture
- Support for recharge
  - Arizona's priority is last
  - Need to prepare for future shortage

# Late 1990s Example

- Rate-setting strategy was consistent:
  - M&I and federal customers pay full cost
  - M&I customers pay capital charge (for repayment)
  - Ag customers pay variable cost only (electricity)
  - Recharge customers partially subsidized
  - Balance = property taxes
  - Reserve levels remain constant

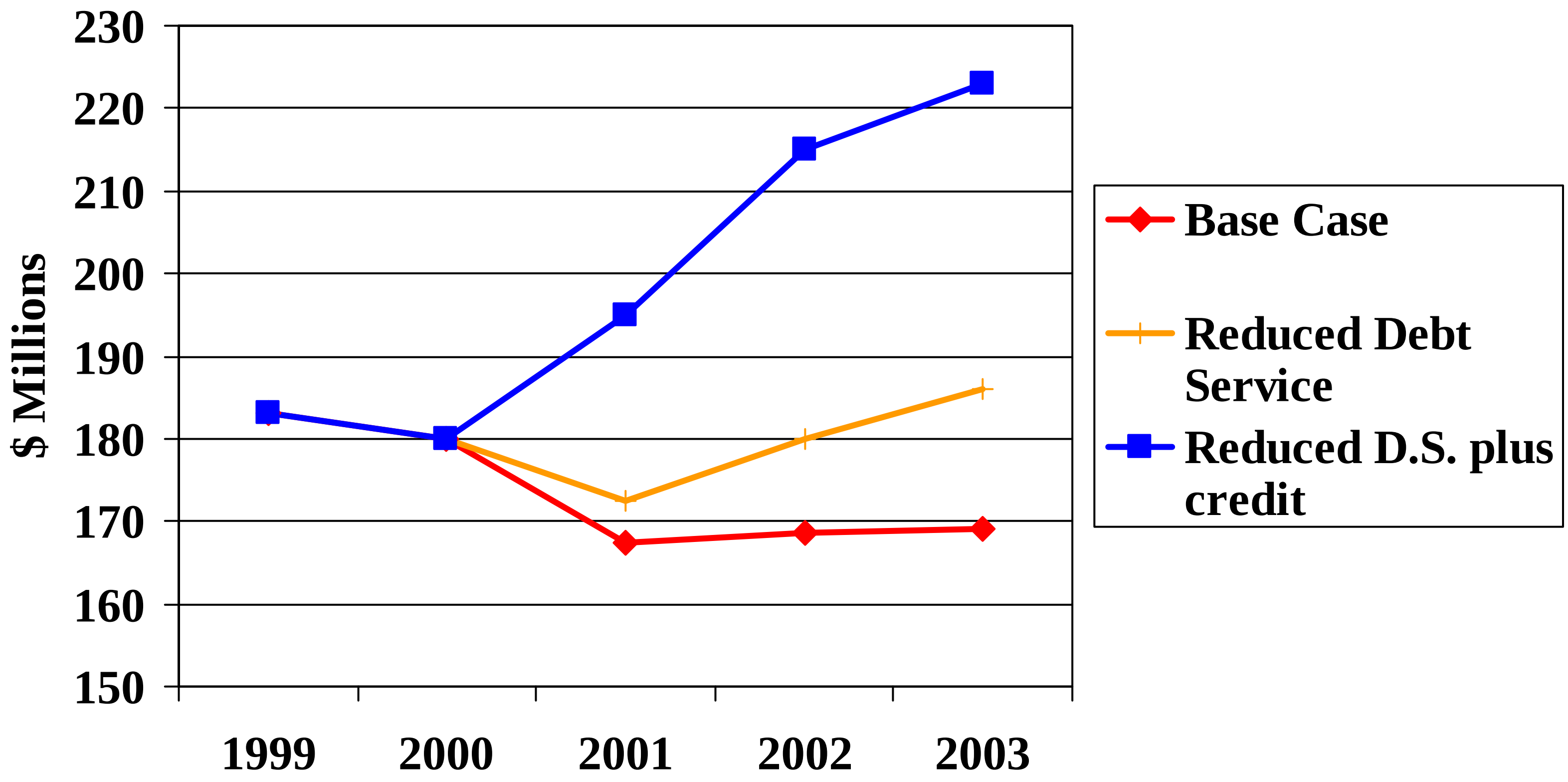
# CAWCD v. U.S.

- Debt repayment conditionally settled for 3 years
- Temporary settlement = savings
- Board passed savings to constituents, reserves untouched

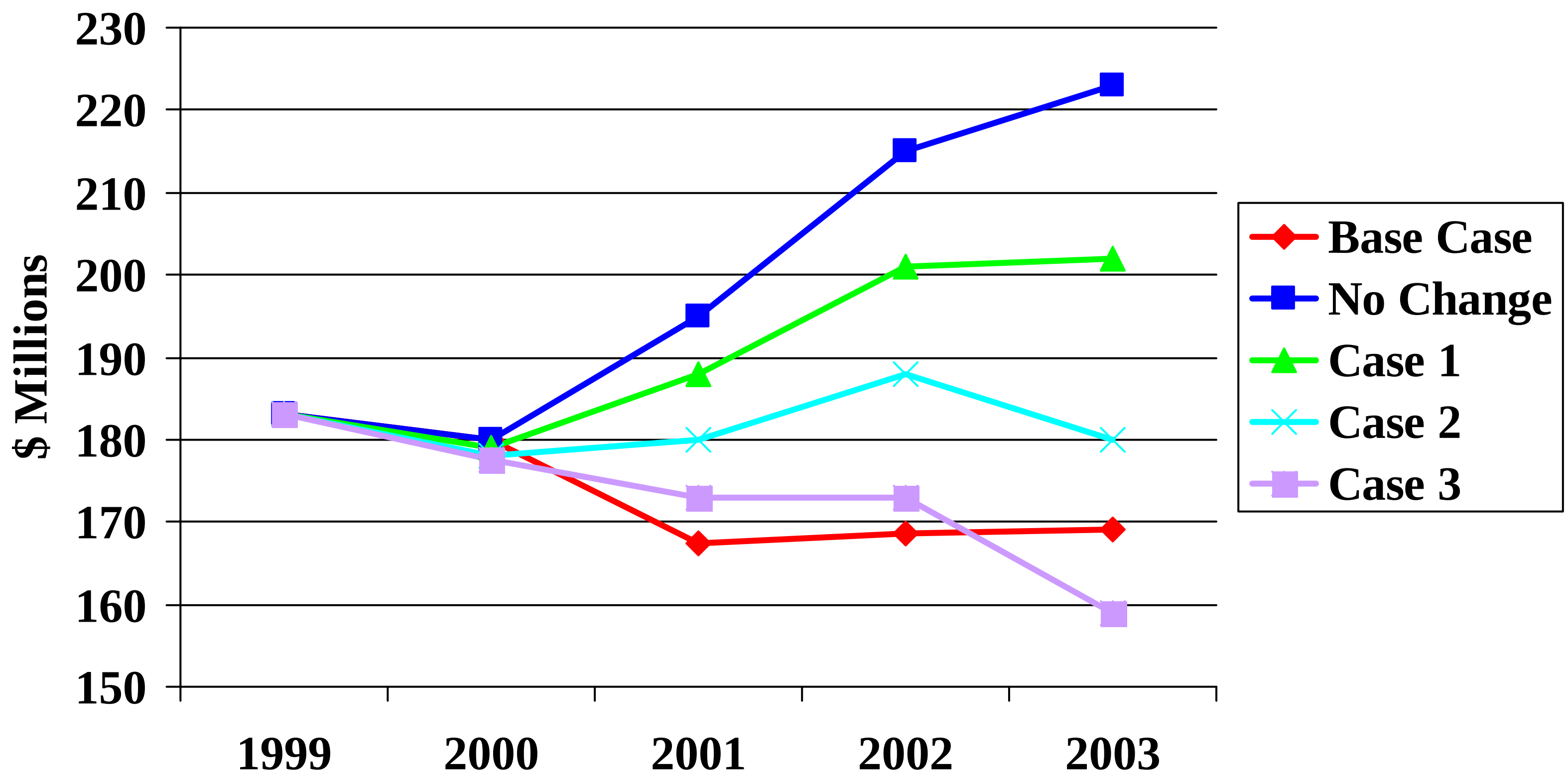
# Analysis of Options (2000)

| | Repayment Obligation | Property Tax Rate | M&I Capital Charge Rate |
|---|---|---|---|
| Base Case | $1.781 Billion | 10 cents per $100 | $48 per acre-foot |
| No Change | $1.65 Billion | 10 cents per $100 | $48 per acre-foot |
| Case 1 | $1.65 Billion | 9 cents per $100 | $43 per acre-foot |
| Case 2 | $1.65 Billion | 8 cents per $100 | $38 per acre-foot |
| Case 3 | $1.65 Billion | 7 cents per $100 | $33 per acre-foot |

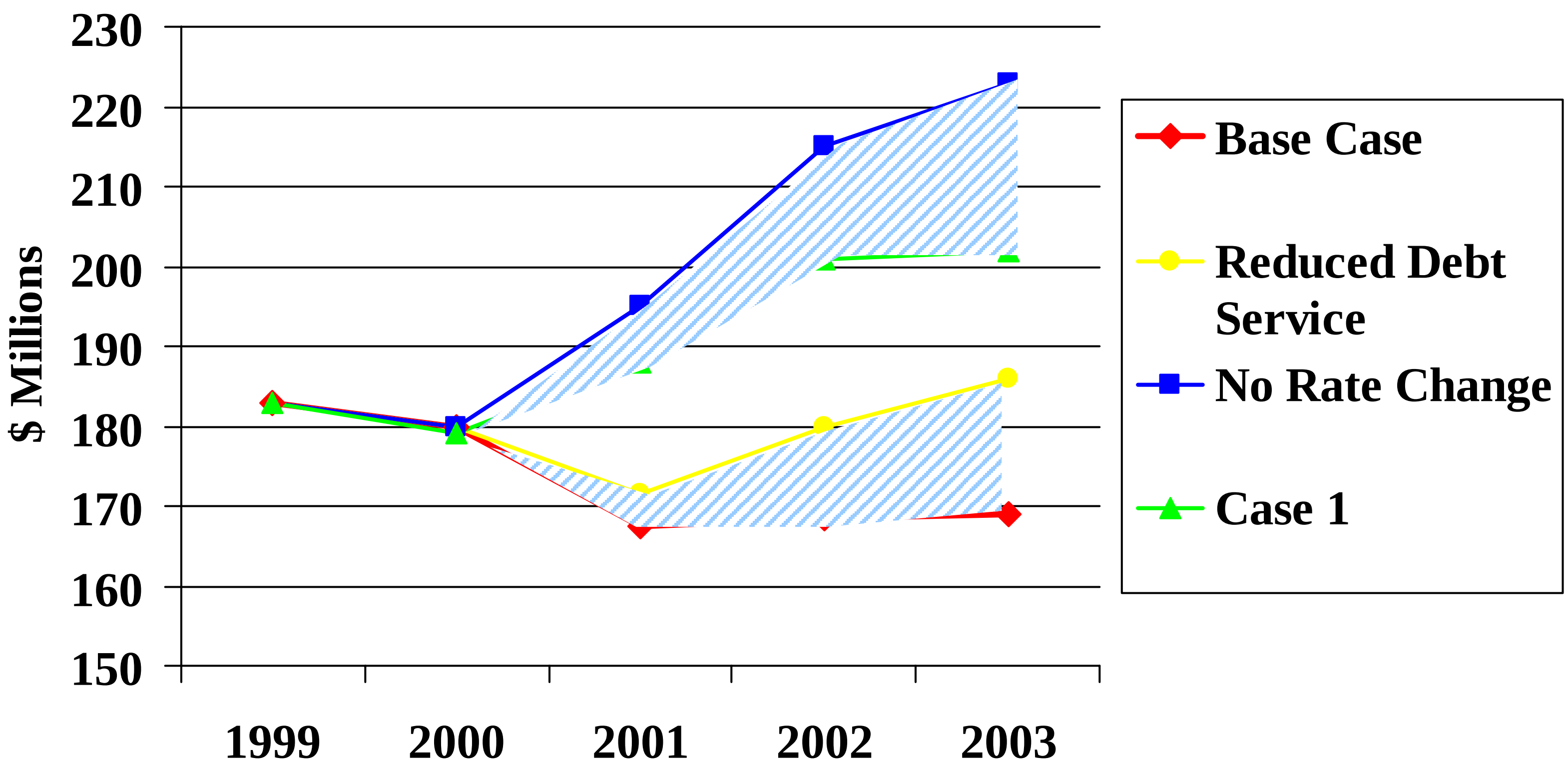
# Unrestricted Reserves (2000)



# Unrestricted Reserves (2000)



# Unrestricted Reserves (2000)



# 2003 Example

- Settlement extended until 2011
- Eliminated financial uncertainty
- Board decided to reduce reserves by 20%
- Reduced property taxes and capital charges

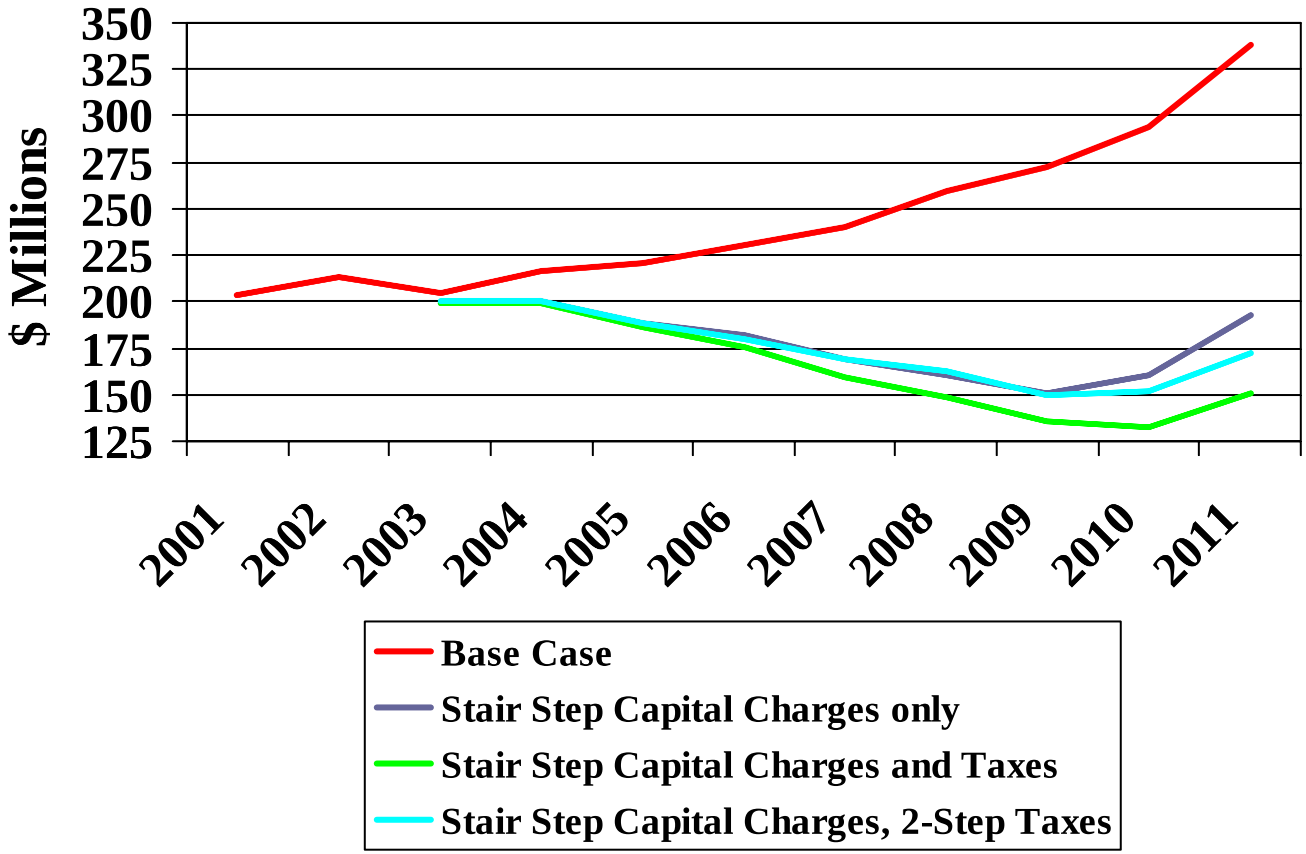
# An Example

- Delivery rates have a reconciliation mechanism based on actual costs
- If delivery rates were reduced below cost, the reconciliation would correct for it
- Capital charges are constrained by federal repayment
- Property taxes allow fine tuning without modifying delivery rates (cost recovery)

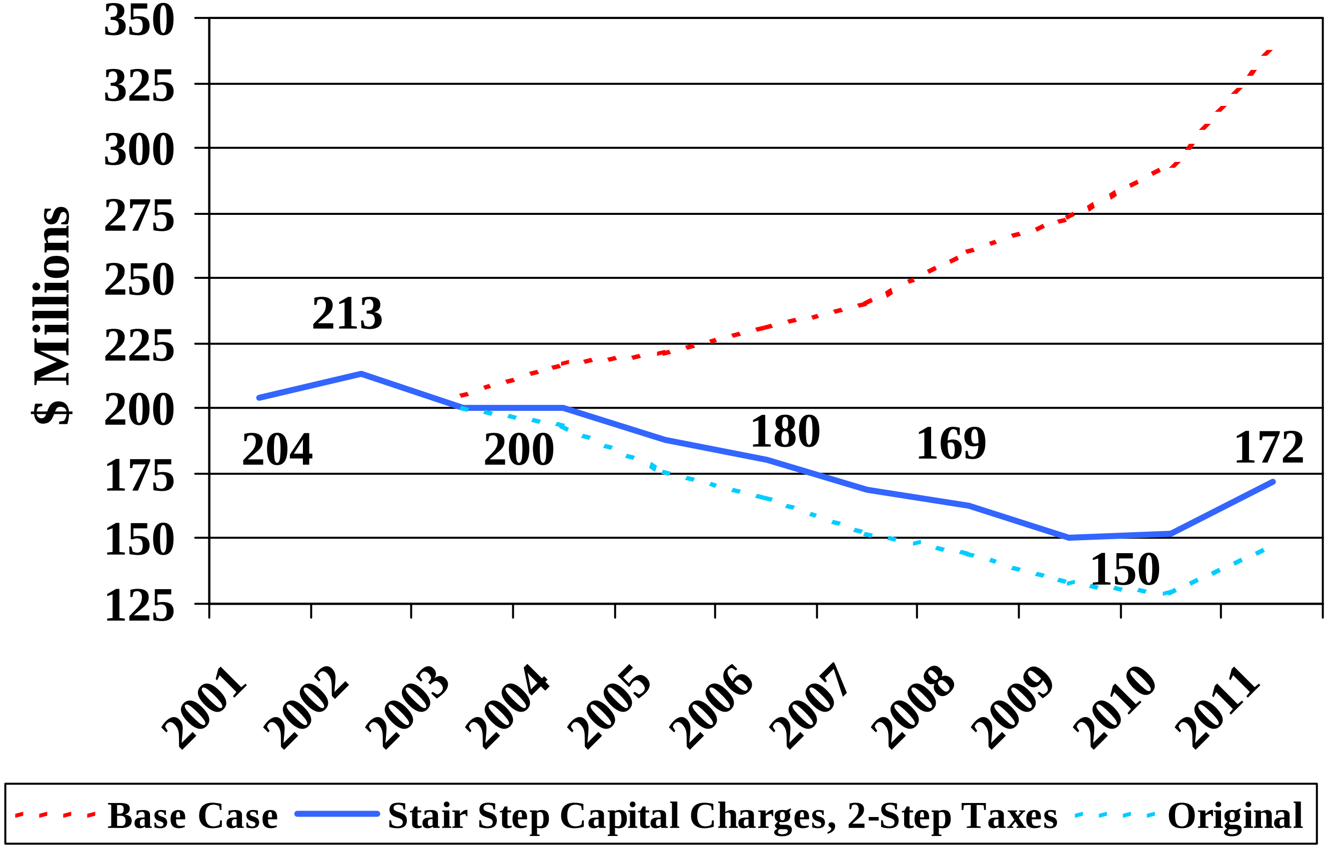
# Options Explored (2003)

- 10 cases in all
  - Stair step Capital Charges only
  - Stair step both Capital Charges and Property Taxes
  - Stair step Capital Charges, two or three step Property Taxes

# Options explored – examples (2003)



# Revised Staff recommendation (2003)



Initial settlement in 2000 resulted in rate reductions in 2001

Settlement extension in 2003 resulted in more rate reductions

| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|---|
| Property Tax Rate | 0.10 | 0.09 | 0.09 | 0.09 | 0.08 | 0.08 |
| Property Tax Revenues ($M) | 23.6 | 24.2 | 27.1 | 27.3 | 27.9 | 30.3 |
| Capital Charges ($/acre-foot) | 48 | 43 | 43 | 37 | 32 | 28 |
| Capital Charge Revenues ($M) | 28.3 | 25.4 | 28.6 | 25.8 | 18.5 | 16.2 |
| Change in Reserves ($M) | - | (11.0) | 9.0 | (8.0) | (13.0) | (17.0) |
| Reserves ($M) | 215 | 204 | 213 | 205 | 192 | 175 |

Reserves decline

# For More Information

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