AGI
TECHNOLOGIES

A Report Prepared For :

Snohomish County Public Works Department
2930 Wetmore Avenue
Everett, Washington 98201

PHASE II HYDROGEOLOGIC STUDY AND MITIGATION MEASURES EVALUATION
CATHCART LANDFILL
SNOHOMISH COUNTY, WASHINGTON

May 31, 1995

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Project Hydrogeologist

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AGI Project No. 15,512.108

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EXECUTIVE SUMMARY

This report summarizes AGI Technologies' (AGI) Phase II Hydrogeologic Study and Mitigation Measures Evaluation for the Cathcart Landfill (CLF) in Snohomish County, Washington. Cathcart Landfill is located on the south side of the Snohomish River Valley in Snohomish County, Washington. The landfill comprises approximately 60 acres, within a larger site of approximately 198 acres.

The County currently faces several issues associated with CLF impacts on groundwater and surface water. The key problem is the requirement to treat much larger volumes of contaminated water than expected. Leachate-impacted groundwater is being captured in the landfill's underdrain system. Impacted underdrain water must be pumped to a pretreatment facility for treatment.

In addition, surface water runoff from the northern, older portion of the landfill cap has elevated water quality indicators, including specific conductance, hardness, and sulfate. Runoff from this area combines with runoff from the southern portion of the landfill. Because the combined surface runoff water quality indicators are elevated, this water must also be handled through the pretreatment facility.

These conditions require the County to treat a large volume of water originally intended to be discharged directly to Garden Creek, which flows across the landfill site. With the influx of this additional water, discharge volumes are higher than anticipated and occasionally exceed the County's permitted discharge volumes to the Silver Lake Water District's pumping station. Tank trucks must then be used to transport excess treated water off site to the City of Everett's treatment plant, bypassing the Silver Lake Water District's station. All of this additional treatment represents significant costs to the County.

The primary objectives of this Phase II study included:

- Identify current sources of inflow to the landfill.
- Identify and evaluate alternatives for mitigation of landfill inflows.
- Assess source(s) of landfill cap runoff impacts and possible mitigation alternatives.

Specific tasks completed to accomplish these objectives were:

- Task 1: Historical chemistry, water elevation, and flow data review.
- Task 2: Weir construction and repair.
- Task 3: Deep soil boring drilling and piezometer installation.
- Task 4: Current chemistry, water level, and flow data collection.

- Task 5: Quality assurance review of new chemistry data.
- Task 6: Comprehensive watershed balance and landfill hydrologic budget analysis.
- Task 7: Mitigation measures evaluation.

Based on results of the watershed balance and landfill hydrologic budget analyses, we conclude the following:

- The upgradient portion of the Garden Creek watershed provides a sufficient volume of water to provide the calculated inflows to the landfill. Much of the rainfall in the watershed goes into temporary groundwater storage and effectively increases the saturated thickness of the aquifer at each landfill face during the wet season.
- Groundwater upwelling is a significant source of water to the leachate collection and underdrain systems throughout the year. During the dry season, this inflow is estimated to be a minimum of approximately 6 gpm. Wet season groundwater upwelling (November and December) is estimated to be up to approximately 69 gpm (December), and may be higher during January and February. During the wet season, upwelling volume appears to be at least five times the volume of other inflow sources.
- Groundwater flow through the alluvial channel at the south face of the landfill also appears to be a significant source of inflow. During the dry season, total south face groundwater inflow is estimated to be approximately 4 gpm; during the wet season, this flow increases to an estimated 14 gpm.
- Groundwater flows across the east and west faces of the landfill section are insignificant relative to the south face and upwelling inflows.
- Internal drainage of leachate may be a significant source of landfill fluids, although it is currently impossible to quantify the volume contributed.

GROUNDWATER INFLOW MITIGATION ALTERNATIVES

Based on the results of groundwater inflow evaluation, mitigation alternatives were developed for four groundwater-landfill interface boundaries: landfill south face, landfill west face, landfill east face, and groundwater upwelling. The alternatives were preliminarily screened based on a number of factors, including short- (1 to 5 years) and long-term effectiveness, implementability, environmental impact, regulatory acceptance, and costs (initial and operation & maintenance [O&M]). The preliminary screening eliminated alternatives that have no merit for groundwater control or are obviously extremely difficult or impossible to construct, and identified those alternatives most appropriate for each groundwater-landfill interface boundary. After the preliminary screening, a more detailed final evaluation was performed. This evaluation judged the alternatives with respect to three criteria: construction and O&M costs, savings in leachate management costs, and potential for environmental mitigation.

Performance and cost were the primary criteria used during final evaluation of alternatives. In addition to these criteria, the alternatives were considered in terms of their potential to mitigate landfill-related impacts on groundwater.

Alternatives for mitigation of groundwater inflow are listed below.

No Action : No action. Continue to treat/pump water as currently handled.

Line East Ditch : Line east ditch with a geomembrane or low-permeability soil to reduce surface water infiltration into groundwater. The collected water could be discharged downstream of the North Pond or directly into the North Pond. Minor flow diversion would be achieved.

Line Garden Creek : Line Garden Creek along its reach through the landfill with a geomembrane to reduce surface water infiltration. Low-permeability soils could also be used as the lining material. Minor flow diversion would be achieved.

Line South Pond: Construct an impermeable flexible membrane liner at the base of the South Pond to reduce leakage into the southern end of the landfill.

Interceptor Trench : Excavate an interceptor trench to collect groundwater as it enters the landfill perimeter.

Slurry Wall : Excavate a deep trench and fill with a low-permeability bentonite-cement slurry, making a wall to prevent groundwater migration across the boundary.

Grouting : Inject grout in a series of borings around the upgradient perimeter of the landfill to produce an impermeable wall similar to a slurry wall. Inject grout under high pressure beneath the base and sides of the landfill to create a horizontal seal, thus preventing groundwater from entering the landfill. This alternative is considered to be difficult and costly.

Horizontal/Directional Drilling : Horizontal bore "micro tunnels" below the long axis of landfill, to provide drainage for groundwater flow entering area of landfill.

Soil/Rock Fracturing: Drill borings in a linear pattern and place inflatable packers in holes. Packers would be inflated and air or water injected at high pressure to fracture soil and rock, creating permeable zones and allowing preferential flow pathways.

Extraction Wells : Install extraction wells at appropriate locations around the landfill to reduce the water table elevation around and under the landfill.

None of the evaluated alternatives is cost effective in terms of reducing leachate management costs. Of the two alternatives that would be most successful in reducing leachate pretreatment volumes (deep trench and extraction wells/rock fracturing), the extraction wells/rock fracturing alternative has the lower net present cost ($10,306,000). This alternative also has the lower ratio (5.7:1) of present value of costs:present value of avoided costs; hence, its cost per gallon of avoided leachate would be lowest. This alternative also appears to have the greatest potential for supplemental groundwater control, if needed for cleanup of landfill-related groundwater contamination.

We recommend the no action alternative be implemented unless unforeseen events significantly change the values in the cost analysis. However, diversion of the runoff from the landfill cap should be continued to the fullest extent possible to minimize total leachate management costs. To reduce total costs associated with continued treatment under the no action alternative, we evaluated two additional options for purchasing additional disposal capacity. The first includes doubling the current disposal capacity to eliminate or reduce the need for costs associated with effluent off-hauling and trucking and allow for eventual Regional Landfill effluent requiring pretreatment; the second includes increasing current disposal capacity approximately 20,000 gallons per day in order to eliminate off-hauling and trucking. Based on these evaluations, we further recommend the County purchase 20,000 gallons per day additional disposal capacity to convey effluent that is currently off-hauled and trucked to the City of Everett. Costs associated with this option under the no action alternative are the lowest in terms of net present value of the alternatives considered in our evaluation.

SURFACE WATER MITIGATION ALTERNATIVES

Alternatives for mitigation of surface water are listed below.

Continue the present discharge practice: Conductivity, sulfate, and hardness declined considerably since the cap was placed. This decline tends to indicate a one-time source that is being flushed from the cap soils by precipitation. Given this decline, discharge to the North Pond or Garden Creek as much as possible remains a viable alternative.

Construct a separate stormwater detention pond for the cap runoff: This pond may be appropriate if cap discharge to the creek is allowed at all times. This would prevent further contamination of cap runoff by contaminated groundwater, and facilitate discharge to the creek. Necessary storage capacity would need to be evaluated with respect to available space.

Obtain a regulatory variance for Garden Creek discharge: Apply for a variance to discharge surface water having conductivity, sulfate, and/or hardness exceeding action levels to Garden Creek. If necessary, this application could be supported by the results of a screening level environmental risk assessment.

Treat cap runoff: The cap runoff could continue to be treated in the on-site pretreatment facility and discharged with leachate to a publicly-owned treatment works (POTW). The pretreatment/ POTW system is intended for a much higher concentration of contaminants, and is inherently a more expensive treatment than necessary.

Other options include filtration/ion exchange, consisting of running the water through a deep bed sand filter and then through an ion exchange system. The ion exchange would be similar to an industrial ion exchange/water softening system. The system could include equalization ponds and large ion-exchange units.

By far the most cost-effective alternative is to continue to discharge cap runoff through the North Pond to Garden Creek as much as possible. If and when that is not possible, we recommend applying for a permit variance, with the possible support of an environmental risk assessment if necessary. An internal review of cap runoff discharge procedures could help determine when and if it might be necessary to begin the application process. If that process is not successful, it would be cost-effective to develop the filtration/ion exchange and de-ionization alternative on a lease or rental basis, and continue to discharge through the North Pond to Garden Creek. A new, separate stormwater detention pond may facilitate implementation of either a variance or treatment.

1.0 INTRODUCTION

1.1 GENERAL

This report summarizes AGI Technologies' (AGI) Phase II Hydrogeologic Study and Mitigation Measures Evaluation for the Cathcart Landfill (CLF) in Snohomish County, Washington. Our services were provided to Snohomish County (County) under Master Agreement 9270, Work Authorization No. 4.

1.2 SITE DESCRIPTION

Cathcart Landfill is located on the south side of the Snohomish River Valley in Snohomish County, Washington, as shown on **Figure 1**. The landfill comprises approximately 60 acres, within a larger site of approximately 198 acres. The boundaries of the site coincide with County property boundaries.

The Snohomish County Regional Landfill and a leachate pretreatment facility, both new facilities constructed in 1992, are located on County property west of the site (**Figure 2**). The Regional Landfill has not yet begun operation. The pretreatment facility is designed to handle effluent from both the Regional Landfill and the CLF. It currently treats water from the CLF.

Refuse placement began at the CLF in 1980, and continued through June 1992, when the landfill was permanently closed. An historical timeline for the CLF is presented in **Appendix A**.

Stormwater detention ponds are located north and south of the landfill (North Pond and South Pond, respectively), and a creek (Garden Creek) flows from south to north through the site. A landfill gas treatment facility is located south of the landfill. Access to the landfill is via a paved road which extends westward from State Highway 9. A paved road extends along the west edge of the landfill and provides access to the North Pond area. Current site features are shown on **Figure 3**.

The County property is largely forested outside the immediate area of the two landfills. Residential areas generally surround County property, except to the north, where development is sparse.

The site and surrounding area occupy a moderately sloped bench, bordered to the south by steeper slopes extending upward to a broad upland, and to the north by steeper slopes extending downward to the Snohomish River Valley floor. Garden Creek flows northward down and across the bench in a relatively open channel. At the CLF, it enters an excavated ditch and passes around the west side of the landfill. Below the landfill, the stream gradient and the sides of the channel steepen abruptly. The landfill is located directly astride the original creek channel. **Figure 4** shows the topography of the site and surrounding area prior to landfill development. The current topography is similar outside the CLF.

1.3 NATURE OF THE PROBLEM

The County currently faces several issues associated with CLF impacts on groundwater and surface water. The key problem is the requirement to treat much larger volumes of contaminated water than expected. Specifically:

- Leachate-impacted groundwater is being captured in the landfill's underdrain system. This system was originally designed to drain directly to Garden Creek via the North Pond; however, impacted underdrain water must now be pumped to the pretreatment facility for treatment.

- Leachate is captured in the landfill's leachate collection system and must be treated at the pretreatment facility. Placement of a synthetic cap over the landfill by 1992 was expected to reduce leachate volumes; however, leachate volumes are not diminishing as expected.

- Surface water runoff from the northern, older portion of the landfill cap has elevated water quality indicators, including specific conductance, hardness, and sulfate. Runoff from this area combines with runoff from the southern portion of the landfill and discharges to the North Pond. Because the combined surface runoff water quality indicators are elevated, this water must also be handled through the pretreatment facility.

- Leachate-impacted groundwater seeps into the north stormwater detention pond (North Pond) located hydraulically downgradient of the landfill. This requires that surface water in the North Pond be pumped and handled through the pretreatment facility rather than discharged directly to Garden Creek, as originally intended.

These conditions require the County to treat a large volume of water originally intended to be discharged directly to Garden Creek. With the influx of this additional water, discharge volumes are higher than anticipated and occasionally exceed the County's permitted discharge volumes to the Silver Lake Water District's pumping station. Tank trucks must then be used to transport excess treated water off site to the City of Everett's treatment plant, bypassing the Silver Lake Water District's station. All of this additional treatment represents significant costs to the County.

AGI completed a Phase I study of the groundwater inflow problem in 1994. The study concluded that there were a number of potential sources for the excess volumes of water captured in the leachate and underdrain lines. These sources included leakage from Garden Creek, leakage from the South Pond, leakage from the east drainage ditch, and groundwater inflow through more permeable zones in bedrock underlying the landfill. The study also confirmed previous studies that indicate leachate has contaminated the groundwater beneath the landfill. Mingling of waters from the leachate line and underdrain system is contributing to the continuing production of leachate and to the contamination of groundwater in the underdrain.

The Phase I study also concluded that excess fertilizer application to the landfill cover soils may have caused the water quality problem in cap runoff.

Based on these findings, AGI recommended a Phase II study be conducted to determine the sources of the additional water, to evaluate means to reduce flow from these sources, and to further examine cap runoff water quality issues.

1.4 PURPOSE AND SCOPE OF SERVICES

The objectives of the Phase II study included:

- Identify current sources of water inflow to the landfill.
- Identify and evaluate alternatives for mitigation of landfill inflows.
- Assess landfill cap runoff impacts and possible mitigation alternatives.

Specific Phase II tasks to accomplish these objectives are summarized below.

- *Task 1* - Historical Chemistry, Water Elevation, and Flow Data Review

  A large amount of historical data has been generated over the life of the CLF, primarily by the County's ongoing monitoring program. For this study we compiled and reviewed historical data, primarily from the time of landfill closure (1991) to present. These data included:

  — groundwater chemistry
  — surface water chemistry
  — groundwater level data
  — leachate and underdrain flow data
  — precipitation data

  Our review of these data focused on identifying and interpreting trends at the CLF.

- *Task 2* - Weir Construction and Repair

  Our Phase I study indicated significant volumes of groundwater and leachate were commingling beneath the landfill, likely due to perforations in the landfill liner. The source of the groundwater was uncertain, but was suspected to be due, in part, to seepage from the south and Garden Creek. To assess whether inflow from the pond and creek was occurring, we constructed four new V-notch weirs in Garden Creek along the landfill's west side, repaired an existing weir located downstream of the landfill, and measured flow on five occasions to identify losses between weirs. The locations of the weirs are shown on **Figure 3.** Weir construction and installation details are provided in **Appendix B.**

- *Task 3* - Deep Soil Boring Drilling and Piezometer Installation.

  To explore subsurface conditions and identify water-bearing zones potentially draining laterally into or beneath the CLF, we drilled seven borings and installed seven piezometers along the landfill's east and south perimeters. Logs of the piezometer borings are included in **Appendix C.**

  A total of 32 wells and piezometers currently exist at the CLF. Their locations are shown on **Figure 3.**

- *Task 4* - Current Chemistry, Water Level, and Flow Data Collection

  County personnel regularly collect surface water and groundwater samples for chemical analysis, measure groundwater levels, and monitor landfill fluid discharge volumes. Task 4 was designed to make recommendations to the County, based on our review of historical data, for modification of current sampling and monitoring protocols. Such a program will optimize the development of a concurrent database to evaluate temporal and spatial trends.

- *Task 5* - Quality Assurance Review of New Chemistry Data

  Task 5 consisted of a quality assurance/quality control review of fall 1994 and winter 1995 laboratory analytical results.

- *Task 6* - Comprehensive Watershed Balance and Landfill Hydrologic Budget Analysis

  A watershed balance and landfill hydrologic budget were developed to identify inflows to the landfill contributing to the total flows requiring treatment. This task specifically included the following subtasks:

  - Calculating a water balance for the Garden Creek watershed. The watershed balance was developed to determine whether sufficient groundwater recharge and throughflow was available to account for the volume of water collected in the leachate and underdrain lines.

  - Conducting a hydrologic budget analysis for the landfill. This analysis was conducted to quantify inflow volumes from the various sources contributing to the water collected in the leachate and underdrain lines. For this analysis the landfill was reduced to a conceptual model that included inflow and outflow components. Inflows were solved for using the outflow data from the County and flow parameters determined by the watershed balance.

- *Task 7* - Mitigation Measures Evaluation

  Using the results of Task 1 through 6, we reviewed and evaluated alternatives to mitigate landfill effluent volumes requiring treatment at the pretreatment facility. This evaluation focused on reducing inflow to the landfill and improving cap runoff quality if possible. Potential mitigation measures were screened based on technical feasibility and cost.

1.5 PREVIOUS INVESTIGATIONS

Many geotechnical and hydrogeologic investigations have been completed at the CLF and neighboring Regional Landfill; information pertinent to and used by AGI during the Phase II study are summarized in the following reports and drawings (listed in chronological order):

- *Construction and Contract Documents and Drawings for Stages 1 and 2, 3 and 4, and 5 and 6* (Snohomish County Department of Public Works, Solid Waste Division, various dates).

- *Cathcart Landfill Snohomish County Special Report* (Stetson, Anderson, and Tanaka, 1981).

- *Letter report to Snohomish County Public Works Department* (Converse Consultants, NW, 1988).

- *Summary Report of Geologic Investigations, Snohomish County Regional Landfill - Volumes I and II*; Sweet-Edwards/Emcon, Inc., December 1988.

- *Variance Request; Snohomish County Cathcart Landfill*; Sweet-Edwards/Emcon, Inc., November 1989.

- *Phase II Hydrogeologic Study* (Converse Consultants, NW, 1989).

- *Hydrogeologic Study, Snohomish County Regional Landfill, Snohomish County Washington*; Converse Consultants Northwest, July 1991.

- *Cathcart Landfill Water Balance Investigation* (Converse Consultants, NW, 1991).

- *Phase III Hydrogeologic Investigation* (Converse Consultants, NW, 1991).

- *Geologic Logging, Construction Observation, and Operational Recommendations for Monitoring Wells W-2 and G16-S and Gas Probe GP-5* (Golder Associates, 1992).

- *Summary Report, Comprehensive Hydrogeologic and Engineering Study - Phase I, Cathcart Landfill, Snohomish County, Washington* (AGI Technologies, February 2, 1994).

- *Summary Hydrogeologic Report, Regional Landfill, Snohomish County, Washington* (AGI Technologies, April 1995).

2.0 LANDFILL HISTORY AND OPERATIONS

2.1 PRE-DEVELOPMENT CONDITIONS

The CLF is centrally located within a drainage basin that encompasses surface water runoff from the approximately 700-acre Garden Creek watershed. **Figure 4** delineates the approximate watershed area. Surface water from within the Garden Creek watershed drained to the original creek channel prior to CLF development, at which time the creek was redirected along the landfill's west side. Garden Creek reenters its original channel north of the CLF and flows northward to the Snohomish River Valley and thence to the Snohomish River, located approximately 1-1/2 miles north of the CLF.

2.2 LANDFILL DEVELOPMENT

CLF design and initial site preparation took place in the late 1970s. **Figure 5** shows the CLF relative to the original site topography. Site preparation included cutting into the sides of Garden Creek drainage and creating a relatively flat base for the landfill by filling the stream channel. Garden Creek was redirected from its natural channel to a ditch along the CLF's west side (see **Figure 2**) and rejoins the original channel approximately 700 feet north of the landfill.

Redirection of Garden Creek included constructing the South Pond (see **Figure 2**) to reduce Garden Creek flow rates during peak flows. The South Pond was constructed by damming Garden Creek with an earth-filled dam and compacting low permeability sediments at the bottom of the pond. Site preparation also included construction of the North Pond (**Figure 2**). The North Pond was created by blocking the former Garden Creek channel with an earthen dam constructed with a bentonite clay core. The North Pond is designed to discharge into Garden Creek through a line exiting the pond bottom or by an overflow at the pond's north end.

The CLF was constructed in six stages, beginning with Stages 1 and 2 at the landfill's north end in 1979. Landfill design included underdrains and leachate collection lines to limit the impact of refuse on the hydrologic environment. These lines are shown on **Figure 6**. Stage 1 and 2 construction included:

- Installing a tight line underdrain along the centerline of the CLF prior to liner installation to drain incidental surface water ponded at the upstream (south) edge of the landfill excavation. Ponded water entered the underdrain through a catch basin, was conveyed beneath the developed stages, and discharged to the North Pond.

- Placing a 30-mil polyvinyl chloride (PVC) liner directly on the bedrock or backfill and a 30-mil Hypalon liner along the CLF's sides. Liner seams were field-welded by the installation contractor.

- Installing a leachate collection system on top of the liner and two pretreatment lagoons at the north end of the CLF for treating collected leachate. The leachate collection system comprises a network of perforated pipes that feed into a tight line along the center of the CLF. The leachate collection piping exits the north end of the CLF and discharges into a lift station, from which leachate was originally designed to be pumped to the two north lagoons for pretreatment.

Groundwater seepage pressures reportedly caused liner upwelling in the Stage 1 and 2 area. Most of the upwelling was reportedly along the east side of the landfill excavation. County construction notes indicate the liner was subsequently cut in numerous locations to relieve upward hydraulic pressures. Stetson, et al.[1] reported some of these cuts were fitted with one-way relief valves designed to permit only upward flow through the liner. County personnel reported all liner cuts were subsequently field repaired prior to placing refuse. The Stetson report states that lateral perforated underdrains were then retrofitted along the flanks of Stages 1 and 2 to convey upwelling groundwater to the centerline underdrain.

Refuse placement commenced in approximately 10-foot lifts after liner preparation and placement of the lateral drains. County personnel stated that heavy equipment periodically contacted and ripped the liner as the refuse was placed; it is not clear whether these rips were repaired. In Stages 1 and 2, once a height of refuse (established by the County as 10 feet) sufficiently heavy to hold the liner down was reached, the perforated lateral drains were permanently sealed with grout. The centerline underdrain was not grouted.

As refuse placement commenced in Stages 1 and 2, liner placement for Stages 3 through 6 progressed two stages at a time. The design drawings and specifications indicate Stage 3 through 6 construction was similar to that for Stages 1 and 2. The underdrain was progressively extended southward and fitted with catch basins at the upstream edge of each developed stage to drain ponded surface water. The catch basins were removed and their points of attachment to the underdrain were sealed upon development of each successive stage. Perforated lateral drains were incorporated into landfill design and installed beneath the liner in Stages 3 through 6 to convey groundwater to the centerline underdrain. However, construction notes indicate upwelling and liner flotation occurred in Stages 3 through 6 despite these efforts. Most upwelling was again reportedly along the east side of the landfill excavation. County records indicate the lateral drains beneath Stages 3 through 6 were not grout sealed as they had been in Stages 1 and 2.

Although some reports conflict, County personnel have stated that significant seepage occurred along the landfill's south face during construction of Stages 5 and 6. This seepage reportedly appeared to be caused by surface water leakage from the South Pond, and was initially collected in a catch basin and conveyed via the underdrain to the North Pond. County personnel indicate that this water was later pumped to a catch basin constructed at the surrounding grade elevation and piped to Garden Creek through a culvert.

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[1] Stetson, John; G. Anderson; H. Tanaka. March 6, 1981. Cathcart Landfill, Snohomish County - A Special Report.

2.3 LANDFILL CLOSURE

When each of the landfill stages was filled to design capacity, each was closed and covered. Because impacts from the landfill on groundwater and surface water were suspected early on during refuse placement in Stages 1 and 2, various investigations were conducted by the County to identify and characterize these impacts. Specific closure measures and pertinent investigation activities are summarized in an historical timeline presented in **Appendix A.**

2.3.1 *Chronology*

Stages 1 through 6 of the landfill were filled to design height by the spring of 1990. At that time, the County began closure of the CLF in accordance with applicable state and federal regulations, including placing a low permeability soil cover over the refuse. The soil cover was completed for Stages 1 through 4 by January 1991. Stages 1 and 2 were later capped with a synthetic flexible membrane. Placement of this liner was completed by November 1991. To accommodate an ongoing need for refuse disposal, the County obtained a conditional use permit for vertical expansion of Stages 3 through 6, and refuse placement continued in those stages through June 1992. Stages 3 through 6 were then closed and capped by November 1992.

2.3.2 *Landfill Cap*

The landfill cap is constructed with a combination of low permeability earthen fill and either high density polyethylene (HDPE) or very low density polyethylene (VLDPE) geomembranes. Cap design was modified to include a low permeability compacted soil layer after construction of Stages 1 and 2. Specific design components were layered as follows:

Stages 1 and 2

- 12 inches topsoil
- Non-woven geotextile
- 12-inch drainage layer
- 60-mil HDPE geomembrane
- 3-inch foundation layer or 16-ounce geotextile
- 12-inch (minimum) general earth fill

Stages 3 through 6

- 12 inches topsoil
- Non-woven geotextile
- 12-inch drainage layer
- 40-mil VLDPE geomembrane
- 18-inch compacted soil layer (permeability 10^{-5} cm/s)
- 12-inch (minimum) general earth fill

Lined surface water drainage ditches were constructed on the landfill cap to collect cap runoff and convey it to a central discharge point at the landfill's north end. Cap runoff was originally designed to drain to the North Pond. Due to water quality problems with the runoff, it was plumbed for optional diversion directly into the landfill fluids conveyance system. With improvements in runoff quality, this diversion has been discontinued and runoff currently enters the north pond. A schematic of the surface water drainage and discharge system is shown on **Figure 7**.

2.3.3 *Leachate Conveyance and Pretreatment Facility*

Effluent Treatment Lagoons: Two pretreatment lagoons were constructed at the landfill's north end (see **Figure 3**). The northernmost of these lagoons was abandoned and removed in the spring of 1990, as it was thought to be leaking and impacting underlying groundwater. The second lagoon was rebuilt as an overflow containment basin for leachate from the pipeline and no longer serves as a treatment lagoon.

Pretreatment Facility: The County constructed the pretreatment facility to replace the pretreatment lagoons and treat fluids from both the Regional Landfill and CLF. This facility was on-line by November 1992. The pretreatment facility's current capacity allows for treatment and discharge to the Silver Lake Water District sewerline of up to 144,000 gallons of effluent per day. Flows in excess of this volume are pumped from the pretreatment facility and hauled by tanker truck directly to the wastewater treatment plant in Everett.

Landfill Fluids Conveyance: Fluids from below and within the CLF are currently captured and conveyed to the pretreatment facility by the landfill underdrain and leachate collection systems. The leachate collection system collects leachate from immediately above the landfill liner and conveys it to collection sump SP-1 at the north end of the landfill, from which it is pumped directly to the pretreatment facility. The location of SP-1 is shown on **Figure 6**. The landfill underdrain system collects groundwater from below the landfill liner. This system was originally designed to convey water to the North Pond, but was rerouted to collection sump SP-4 in 1989 due to poor water quality. SP-4 now flows to SP-1 and is pumped to the pretreatment facility. Outflow from the pretreatment facility is routed through collection sump SP-3.

All other inflows to collection sumps SP-1 and SP-4 are shown schematically on **Figure 8** and are listed below.

SP-1	SP-4
Leachate Collection System	Underdrain
Cap Runoff	North Pond Pumpage
Extraction Well (W-1)	
Landfill Gas Condensate	

2.3.4 *North Pond Modification*

In 1990, the County removed sediment accumulated in the North Pond and deepened it to increase water storage capacity and thus accommodate additional surface water runoff from the landfill cap.

2.3.5 *Landfill Gas Collection and Combustion*

The CLF generates a significant amount of landfill gas. The County operates a gas venting and combustion (flare) system to capture and destroy the gas. Gas extraction piping was installed and the flares ignited in 1990 during Stages 1 and 2. Extraction piping was extended into later stages as CLF closure progressed through 1992. The gas extraction system was expanded and a fourth flare added in 1994.

2.3.6 *Groundwater Extraction*

The County began operating a groundwater extraction well (W-1; see **Figure 3**) in December 1989 at the north end of the CLF to reduce the inflow of leachate-impacted groundwater into the North Pond. W-1 went dry in November 1990, apparently after the water table was lowered due to dewatering of the North Pond for the referenced pond modification. Since that time, the north stormwater pond level has been allowed to rise, making W-1 usable as an extraction well. In February 1992, the County installed a second extraction well, W-2, east of W-1. W-2, however, was not completed with a pump. Groundwater is currently extracted at approximately 35,000 gallons per day from W-1.

3.0 SITE PHYSICAL CONDITIONS

3.1 GEOLOGY

3.1.1 Regional Geology

The CLF is located in the north-central portion of the Puget Sound Lowland on the north slope of a regional highland centered near Clearview, Washington. The highland is underlain by a sequence of glacial sediments deposited on top of bedrock.[2]

Bedrock of the CLF region is mapped as deep pre-Tertiary metamorphic and igneous rocks (greenstone, quartzite, schist, marble, and gneiss) overlain by shallow early Tertiary sedimentary and volcanic rocks. Shallow bedrock in the CLF vicinity is Tertiary siltstone, sandstone, and shale.

The glacial deposits in the CLF area consist of unconsolidated sediments deposited during the Vashon Stade of the Fraser Glaciation. They include:

- *Advance Outwash*: Lacustrine clays and silts, and fluvial sands and gravels deposited in front of the Vashon glacier during its advance.
- *Till*: Unsorted mixtures of silt, sand, and gravel deposited and compacted by the Vashon glacier.
- *Recessional Outwash*: Sand and gravel meltwater sediments deposited during the retreat of the Vashon glacier.

Additional unconsolidated sediments exist in the region in the form of younger post-glacial lacustrine, fluvial, and mass wasting deposit. Minard[2] refers to the fluvial deposit as Recent Alluvium. A thick deposit of Recent Alluvium fills the Snohomish River Valley.

3.1.2 Site Geology

Bedrock beneath the CLF consists of sandstone and weakly bedded siltstone. Unconsolidated deposits overlying the bedrock include Vashon lodgement till and Recent Alluvium associated with Garden Creek. Manmade fill also occurs at the site, resulting from construction activities.

The distribution of these deposits is shown in cross section on **Figures 9** through **11**. These sections are based on explorations conducted by AGI for this project. The following paragraphs describe the geologic units, in order of increasing age.

Fill : Fill at the CLF consists primarily of dense gray silty and sandy gravels and silty sands derived from local borrow pits completed in till. Fill occurs primarily along the landfill perimeter and is associated with road construction and berms at the north and south ends of the landfill excavation.

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[2] Minard, J.P., 1985, *Geologic Map of the Maltby Quadrangle, Snohomish and King Counties, Washington*, U.S. Geological Survey, Water-Supply Paper 1135, 133 pp.

Recent Alluvium (Qal) : Fluvial sediments located in the existing and former Garden Creek channel comprise the Recent Alluvium. These sediments consist of stream-deposited silt, sand, and gravel.

Till (Qvt) : Till at the CLF comprises both weathered and unweathered zones. Weathered till is typically loose to medium dense, light gray to yellow-brown, silty, fine sand with some medium to coarse sand and gravel. Yellow-orange mottling is often encountered in the weathered till. Unweathered till ranges in color from medium to dark gray and consists of medium to very dense, fine- to medium-grained gravelly silty sand or gravel or fine sandy silt. Till occurs everywhere across the CLF site outside the landfill.

Tertiary Bedrock (Ts) : Bedrock at the CLF is a gray-green, soft to hard, thinly laminated, weakly bedded siltstone that grades into sandstone in some areas. The top of the siltstone is typically more fractured and is weathered. According to Minard,[1] shallow bedrock in the CLF area dips to the northwest. Siltstone underlies the entire CLF.

3.2 SURFACE WATER

3.2.1 Garden Creek and East Side Drainage Ditch Flow

The CLF is located within the approximately 700-acre Garden Creek watershed, as described previously. Garden Creek flows north to the Snohomish River through the broad Snohomish River Valley located approximately 1 mile north of the site. In the portion of the watershed occupied by the CLF, runoff from the west also enters the redirected creek channel. A drainage ditch along the landfill's east side collects runoff from the east (**Figure 3**). The east side drainage ditch flows south toward the South Pond and north toward the North Pond from a divide located near the boundary between landfill Stages 5 and 6. Flow to the north discharges directly to the North Pond. Southerly flow enters a pipe at the south end of the landfill, runs west along and under the paved road, and empties into Garden Creek west of the south pond outlet.

Garden Creek flows most of the year except for the dry months during late summer and early fall (typically August through October). In 1994, the creek was dry throughout this period until late October, when fall rains were sufficient to create continuous flow in the stream channel. Flows measured during this investigation at the weirs in Garden Creek along the length of the CLF are presented in **Table 1**. Weir locations are shown on **Figure 3**.

The east side drainage ditch has a relatively flat gradient, but was observed to contain notable flow after significant precipitation events. The ditch was observed to contain standing water between rainfall events. Flow in the east side drainage ditch was not quantified for this study.

3.2.2 Garden Creek Chemistry

Garden Creek water chemistry data obtained by the County for the period June 1987 through May 1994 were reviewed for this study to identify whether there had been changes in water quality due to the landfill closure. This analysis was not directly related to the primary focus of the Phase II investigation, but was undertaken to support the County's effort to maintain good water quality in Garden Creek.

Our review included all available data, but focused on four analytes considered to be potentially characteristic of landfill impact. These include sulfate, specific conductance, chloride, and turbidity.

Plates D-1 through **D-20** in **Appendix D** are plots of each of the four indicators over the referenced time period for sampling locations A, C, D, F, and J. The sampling locations are shown on **Figure 12.** Trends in these data are briefly summarized below.

- ***Location A (Plates D-1 through D-4)***: Location A is upstream from the landfill and is assumed to represent background conditions, with no landfill-related impacts. Creek water chemistry at location A has been relatively consistent since 1989, although sulfate concentrations have generally declined.
- ***Location C (Plates D-5 through D-8)***: At location C, each of the referenced parameters exhibit an upward trend. Note that Location C was associated with Stage 4 and 5 runoff conveyance. Sampling at Location C was discontinued in January 1992 when these conveyance features were removed. Concentrations became notably more erratic about the time the landfill cap was installed (approximately January 1991), indicating cap installation may have resulted in impacts to Garden Creek. These impacts at location C are likely attributable to surface water sheet flow from the landfill across the west side perimeter road to the creek; AGI personnel have observed these flows during periods of heavy precipitation. The County has recently completed improvements designed to minimize this sheet flow.
- ***Location F (Plates D-9 through D-12)***: Sulfate and turbidity have declined over the referenced time period at location F. Concentrations of the other referenced parameters are relatively constant.
- ***Location D (Plates D-13 through D-16)***: Available data for location D include pre-April 1990 and 1994 sampling results. The 1994 results show all parameters have fallen below corresponding historical concentrations.
- ***Location J (Plates D-17 through D-20)***: Sulfate and turbidity have declined. The other analytes have been relatively consistent. Occasional high values for turbidity and sulfate at location J are likely due to high stream flows during sampling.

Overall, water quality has improved in Garden Creek since 1989. This appears to be due more to upgradient changes in water quality than to closure activities.

Fourth quarter (November and December) 1994 analytical results for Garden Creek samples collected at monitoring locations A, A1, B1, D, D1, F, and J, and at the North Pond were the most recent data available at the time of our study. These are summarized in **Tables D-1** and **D-2 (Appendix D).**

3.2.3 *Landfill Cap Runoff*

As described previously, approximately 85 percent of the surface water runoff from the landfill cap is collected in lined drainage ditches that converge at the landfill's north end. The remaining cap runoff flows from portions of the landfill's east side and southeast corner to the east side drainage ditch. This water flows to the North Pond and Garden Creek (see **Section 3.2.1**). Collected cap runoff is directed to the North Pond for temporary storage and, if clean, allowed to discharge to Garden Creek. Cap runoff in the North Pond mixes with groundwater and other surface waters from adjacent slopes. If contaminated, North Pond water is periodically pumped back to the pretreatment facility by a floating pump.

3.2.4 *Landfill Cap Runoff Chemistry*

The County periodically monitors cap surface water runoff for field water quality parameters, including specific conductance, at the locations shown on **Figure 7**. Cap runoff specific conductance has been of particular concern to the County since this parameter has typically exceeded the water quality criteria established for discharge of CLF site waters to Garden Creek and is used by the County as an indicator parameter to monitor discharge criteria exceedance. The County's current discharge criteria are listed in **Table 2**. The specific conductance discharge criteria level is 700 micromhos per centimeter (μmhos/cm).

Figure 13 shows specific conductance measured at the referenced monitoring locations over the period December 1991 through November 1994. As shown on **Figure 13**, specific conductance measured at locations in Stages 1 and 2 has historically been higher than for runoff from elsewhere on the landfill. The County has speculated that the high specific conductance in Stages 1 and 2 runoff is attributable to liberal application of fertilizer during cap seeding. Current data indicate that by 1994, specific conductance of Stages 1 and 2 runoff has diminished to levels closer to, but still slightly higher than, runoff from the rest of the landfill. Cap runoff specific conductance between December 1991 and November 1994 is shown in a histogram on **Figure 14**. Despite the relative consistency across the landfill, specific conductance of the cap runoff sample collected in November 1994 was above the 700 μmhos/cm discharge criteria.

The most recent laboratory analytical data available for cap runoff collected where the referenced drainage ditches converge (Location L-1) are from December 1993. These data are listed in **Table 2.**

The December 1993 analytical data indicate that in addition to specific conductance, sulfate and hardness are also elevated. Other anionic and cationic species analyzed were not detected at concentrations that would be expected to affect the specific conductance. These data suggest some source of elevated sulfate and/or hardness, such as sulfates and/or calcium salts from fertilizer sources such as ammonium sulfate, may be in soil placed over the synthetic cap.

Two different calculation methods were used to determine possible sources of the specific conductance. The first method employed is an empirical relationship between total dissolved solids (TDS) and specific conductance. The second method calculates specific conductances associated with known values of hardness and sulfate based on additive molar conductance. These methods and their results are described more specifically in **Appendix D.**

The two calculations show that the elevated specific conductivity is likely attributable to sulfate and hardness, and that of the two, sulfate is the major source.

Possible sources of the hardness and sulfates in the cap runoff are:

- **Residual contamination from leachate or condensate seeps which may reside in cover soils and/or cap drainage ditches.** County personnel suspect that prior to improvements to the gas collection and conveyance system in 1994, gas and gas condensate migrated upward through the cap via poorly sealed boots around gas collection pipe penetrations.

- **Fertilizers applied during hydroseeding.** It is not clear whether fertilizers used at the landfill were sulfate based. Ammonium sulfate, if used, would likely have resulted in residues that may be the cause of the current sulfate concentrations.

- **Naturally high solids or metals concentrations in the soil cover.** Soil cover material is from local borrow sources. High hardness in the cap runoff may derive from natural minerals such as calcium carbonate in the sediment cover.

3.3 GROUNDWATER

3.3.1 *Regional Groundwater Occurrence*

Groundwater in Advance Outwash and Tertiary bedrock form large regional aquifers beneath the highland south of CLF.[3] The Advance Outwash is the thickest and most productive aquifer in this region, extending from the CLF area south to Lake Washington. The bedrock is generally much less permeable than the overlying outwash deposits. Consequently, wells completed in bedrock generally provide much lower yields than those completed in the outwash.

Groundwater also occurs regionally within the Snohomish River Valley alluvium. Yields can be quite high from wells completed in the alluvium.

3.3.2 *Site Groundwater Occurrence*

Groundwater at the CLF occurs within the alluvium, till, and underlying siltstone. Groundwater may also accumulate temporarily in near-surface fill during periods of high precipitation.

Previous studies have characterized site groundwater as occurring in two distinct aquifers, termed "upper" and "lower." However, due to the lack of an aquitard between the zones referenced as aquifers, we have termed these water-bearing units "shallow and deep groundwater zones" rather than separate aquifers.

For our study we assumed shallow zone groundwater occurs only in the siltstone and deep zone groundwater occurs in both the siltstone and till. Whereas till typically acts as an aquitard over underlying water-bearing formations due to its low permeability, till and underlying siltstone at the CLF are of equivalent permeability. It is therefore likely groundwater flows through both units similarly, and can therefore be considered semi- or unconfined across the site.

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[3] Newcomb, R.C. 1952. *Ground-Water Resources of Snohomish County, Washington*. Washington, D.C.: U.S. Geological Survey Water-Supply Paper 1135.

Groundwater conditions within the alluvium, till, and siltstone were carefully checked during drilling of seven piezometers in early May 1994. Coordinates and reference elevations for piezometers and wells installed by others are presented in **Table E-1 (Appendix E)**. The till and shallow siltstone did not produce much groundwater during drilling and the soil cuttings removed from the borehole only approach moist. These observations suggested unsaturated low-permeability conditions. However, piezometers screened in the siltstone filled quickly with water after being installed and bailed, indicating that significant groundwater does occur within the siltstone. However, the siltstone permeability does appear to decrease with depth.

Wet to saturated conditions were encountered in the alluvium at the piezometer PZ-5 location. Permeability of the alluvium is likely much higher than the underlying bedrock.

3.3.3 Site Groundwater Flow

Groundwater in the siltstone likely flows primarily through fractures, along bedding planes, and along the interface of the weathered siltstone and till. Groundwater in the alluvium and till preferentially flows through the most permeable areas of these sediments.

Groundwater elevation data from the period January 1991 through November 1994 were compiled and evaluated to determine historical groundwater flow directions and gradients. **Plates E-1 through E-10 in Appendix E** show groundwater elevation hydrographs for wells located on all four sides of the landfill (G-4A, G-8D1, G-8D2, G-9S/D, G-10S/D, G-14S/D, and G-15S) over this time period. Landfill underdrain and leachate line flows are included on these plots for comparison. The hydrographs show that groundwater levels follow similar seasonal fluctuations from year to year.

Figures 15 through 18 show shallow and deep zone groundwater elevation contours and corresponding flow directions for third and fourth quarter 1994 (dry and wet seasons). As illustrated, groundwater flow in both zones generally follows the original Garden Creek drainage, flowing northward across the south end of the landfill and converging toward the original Garden Creek channel beneath the landfill. The landfill excavation intersects groundwater in both zones. This intersection occurs on the landfill's west, south, and east sides, and at the landfill's base. Groundwater seeps into the landfill excavation at each of these interfaces and is captured at least partly by the underdrain. Groundwater also flows out of the landfill excavation, as evidenced by chemical impacts to groundwater downgradient of the landfill (Converse, 1990). North of the landfill groundwater in both zones flow toward the Snohomish River Valley. Previous studies have demonstrated that shallow groundwater discharges in part to the Garden Creek channel north of the site.

Contour maps prepared for each groundwater zone for the 1991 through 1994 period were also evaluated for trends in flow direction. These data indicate flow patterns have been consistent since 1991.

3.3.4 *Groundwater Chemistry*

Historical Trends : The primary focus of the Phase II investigation was to determine sources of and develop mitigation for the excess volume of contaminated water present in the CLF underdrain and leachate lines. However, we also evaluated current and historical groundwater chemistry data to see if some trend in the data would shed light on the excess volume problem. Groundwater chemistry data from approximately March 1988 through May 1994 were available for this purpose.

All of the analyzed data are presented in **Appendix F. Plates F-1** through **F-3** in **Appendix F** are plots of shallow zone groundwater chemical concentrations over the review period for G-1A, G-6A, G-8D1, G-9S, G-10S, and G-15S; Plates **F-8** through **F-14** plot deep zone groundwater chemistry data for G-1D, G-6B, G-7D, G-8D2, G-9D, and G-10D. Total landfill fluids (SP-1) and underdrain (SP-4) chemistry are included on plots of Ammonia, Sulfate, and COD concentration.

Analytical results for the third and fourth quarter 1994 groundwater sampling rounds are also summarized in **Appendix F** in **Tables F-1** through **F-3.** For the quarterly sampling, all CLF monitoring wells are sampled for general parameters, dissolved metals, and volatile organic compounds (VOCs). **Figures 19** and **20** show 1994 groundwater chemical concentrations with distance downgradient from the north end of the landfill (represented by well G-10D). These plots indicate chemical impacts from the landfill diminish significantly within approximately 400 feet of the landfill.

Chemical concentrations remained relatively consistent or increased over time through spring 1994 in nearly all wells. Wells G-9 and G-10, located at the north border of the refuse area of the landfill, particularly exhibit increasing concentration trends. Groundwater chemistry trends and the landfill's influence on groundwater quality are discussed in Converse's Phase II and III hydrogeologic studies.

Sulfate and Chemical Oxygen Demand concentrations in groundwater at many wells in both the shallow and deep groundwater zones appear to be periodically higher than COD concentrations in SP-1 flows. Ammonia concentration in SP-1 flows is generally higher than in groundwater.

The third and fourth quarter 1994 sampling round data were evaluated for accuracy and acceptability. **Appendix F** presents our detailed quality assurance (QA) evaluation of these data. The data were generally acceptable; exceptions regarding holding time exceedances and laboratory contamination and recommendations are included in **Appendix F.**

3.4 LANDFILL FLUIDS

3.4.1 *Flow Volumes*

The County monitors liquid flow volumes from a variety of sources at the CLF. We compiled and analyzed this flow data to estimate the relative magnitude of the different sources, evaluate the influence of rainfall, and determine whether volumes have changed with time.

The available data include flow from SP-1, SP-3, SP-4, and W-2, and pumping rates from the North Pond. Flows to and from each of these sources are summarized below:

SP-1: This sump receives leachate from the leachate line, gas extraction system condensate, surface water runoff from the landfill cap, and fluid from SP-4. Fluid in SP-1 is pumped to the pretreatment facility.

SP-4: This sump receives groundwater flow from the underdrain and surface water being pumped from the North Pond. Fluid in SP-4 is pumped to SP-1.

W-2: Groundwater is periodically pumped from this well to SP-1.

SP-3: This sump represents all water discharged through the pretreatment facility to the Silver Lake Water District. It includes flow from SP-1 as well as other sources.

Our analysis of the available data attempted to determine and compare flow volumes for groundwater, leachate, and surface water. Condensate volumes were thought to be insignificant relative to the other fluids and were not considered further. Of the three, only underdrain flow could be quantified with confidence as virtually all of the flow at SP-4 is from the underdrain line.

An attempt was made to quantify leachate flow by subtracting estimated surface water runoff reaching SP-1 and the input volume from SP-4 from total SP-1 flow. However, this computation would not balance for many different months, indicating total surface water and underdrain flow, together, exceeded the total SP-1 flow. This computation does suggest, however, that the total volume of leachate flow must be small relative to the other flows.

Flow data have been compiled into a series of plots. These include **Figures 21** through **24**, which show measured flow volumes from the CLF versus precipitation data for the years 1991, 1992, 1993, and 1994. **Figure 25** combines these data for all years. These five figures show underdrain flow (SP-4), total flow to the pretreatment plant (SP-1), and total flow out of the pretreatment plant (SP-3). Also shown on **Figures 21** through **24** are monthly volumes of total flow minus the volume of calculated cap surface water runoff (SP-1 minus runoff). SP-1 minus runoff was plotted as a further means to evaluate whether final completion of the cap has resulted in the reduction of flows in the underdrain and leachate line. The assumption here is that reduction of rainfall infiltration into the refuse due to cap placement should have resulted in the reduction of fluids captured in the underdrain lines.

Three additional plots (**Figures 26** through **28**) were developed to compare monthly flows for each year in SP-1, SP-3, and SP-4. **Figure 29** shows the calculated contribution of cap runoff to flows in SP-1 between 1991 and 1994.

Pertinent trends in the flow plots are as follows:

- Flow in the underdrain accounts for a large percentage of the total flow reaching SP-1, particularly during August, September, and October. During these dry months, groundwater therefore accounts for most of the flow, suggesting that the contribution from the leachate line is relatively small.
- Underdrain flow volumes do not appear to be declining with time, nor have they been appreciably impacted by completion of the final landfill cap in November 1992.

- Monthly fluctuations in groundwater flows from the underdrain mirror seasonal fluctuations in precipitation. This suggests a direct relationship between rainfall and groundwater recharge to this underdrain.

- The total volume of flow from SP-1 has not changed significantly since 1991. It might be anticipated that completion of the landfill cap in 1992 would result in a net reduction of fluids captured at the landfill over time. This would be true if the rainfall which directly entered the landfill before placement of a cap was now redirected off site. However, this is not the case; at the CLF, surface water runoff does not flow off site, but is either directed to SP-1 via the cap drainage system or rerouted to the North Pond, where some portion of it is later pumped to the pretreatment facility. Consequently, there has been no net change in the volume of water moving through SP-1.

- Additional SP-1 flows, which only include flows discharging from the landfill itself, do not appear to be decreasing.

- Groundwater flow volumes through SP-4 typically range between 1 and 3 millions gallons per month. The highest flows are in the late winter and spring, the lowest during late summer and fall.

- Occasional abrupt changes in flow volumes unrelated to precipitation are due primarily to construction or maintenance activities at the landfill. For example, a basketball removed from the underdrain line in 1992 caused a temporary increase in flow through SP-4. Additional events or activities of this type are presented on the timeline in **Appendix A.**

3.4.2 *Landfill Fluids Chemistry*

A synthetic liner was placed beneath refuse to form a barrier between leachate within the refuse and underlying groundwater. However, as discussed previously, there is considerable evidence that the liner has been physically damaged and allows passage of groundwater into, and leachate out of, the landfill. The result is that leachate is being produced as groundwater enters the landfill and that groundwater captured in the underdrain is contaminated with leachate.

To further evaluate the degree to which the underdrain is being contaminated and whether leachate quality has improved with time since cap placement, SP-1 and SP-4 chemical data from 1987 through 1994 were compiled and analyzed. Available data include COD, ammonia, and sulfate measurements for 1987 to 1994 at SP-1; two COD, ammonia, and sulfate measurements at SP-4; and two rounds of "complete" chemistry for SP-1 and SP-4 collected on December 19, 1993 and September 22, 1994. Results of the complete set of analyses are summarized in **Tables G-1** through **G-5 (Appendix G).** The COD, ammonia, and sulfate data are plotted on **Plates F-3, F-4,** and **F-5,** respectively **(Appendix F).**

The COD, ammonia, and sulfate plots show that concentrations of these parameters have declined with time in SP-1, and may be continuing to decline. The greatest declines occurred before 1990, probably as a result of capping Stages 1 and 2. The continuing decline may reflect improvements in leachate quality entering SP-1, or greater dilution by cap runoff. The data available for SP-4 (groundwater) are not sufficient to determine whether underdrain water quality has improved.

The two rounds of complete analytical chemistry show that SP-1 flow is more impacted by leachate than SP-4 flow. This is expected because the leachate line discharges to SP-1. Concentrations of indicator parameters and detected metals and organic compounds were generally two to three times higher at SP-1 than at SP-4. The concentration of these analytes must, therefore, be considerably higher in the leachate, given that a high percentage of the flow volume at SP-1 is from SP-4.

3.4.3 *Likely Sources of Landfill Fluids*

As stated previously, a significant volume of the fluids exiting the landfill likely enters the system from outside the landfill excavation. Potential sources for landfill flows are summarized below. These inflows are analyzed in greater detail in Section 4.0.

- *Groundwater Throughflow*: The landfill excavation extends below the water table along the landfill's west, south, and east sides. Consequently, groundwater likely enters the landfill along these three sides, plus upward through the landfill base.

- *Leakage from Garden Creek*: Garden Creek is not lined and is dry during the dry season, indicating it is perched above the water table. Surface water may infiltrate through the base of the creek channel and leach groundwater where Garden Creek borders the landfill's south and west edges. This surface water may thereby enter the landfill by contributing to the groundwater throughflow described above.

- *Leakage from East Side Drainage Ditch*: This ditch is not lined; surface water in this ditch may also leak and enter the landfill's east side in a manner similar to that described above for Garden Creek.

- *Leakage from South Pond*: The South Pond is not lined and may lose substantial volumes of water due to leakage. County personnel indicate the pond maintains a minimum level year-round, but typically rises approximately 3 to 4 feet during the wet season. Water leaking from the South Pond may enter the landfill by groundwater flow through the landfill's south face.

- *Construction Features Between the South Pond and the Landfill*: County records indicate several construction features exist in this area, including a culvert used to convey surface water to Garden Creek during construction of Stages 5 and 6, a fire main which exits the South Pond through its north wall and then follows below the road to the east, and the previously referenced drain connecting the east side ditch to Garden Creek. It is not clear whether this culvert or fire main is sealed. All of these features may act as conduits for water seepage through the south landfill face.

4.0 HYDRAULIC EVALUATION

4.1 GENERAL

As discussed in previous sections, an unexpectedly large volume of contaminated water continues to flow from the CLF leachate and groundwater drain lines and must be pumped to the pretreatment facility for treatment. There are two sources of water: groundwater inflow from the sides and base of the landfill and leachate drainage from the refuse.

A hydraulic evaluation was performed to approximate the relative magnitude of various inflow sources. The hydraulic evaluation consisted of a watershed balance and a landfill hydrologic budget. The purpose of the watershed balance was to determine whether sufficient groundwater flow was available to account for the volumes of water captured in the landfill drain lines. Given sufficient groundwater flow, the hydrologic budget analysis was used to estimate inflow volumes from specific areas around the landfill.

The following sections provide a brief introduction to the analysis methods and a summary of the results. A detailed description of the hydraulic evaluations is presented in **Appendix H.**

4.2 WATERSHED BALANCE

The watershed balance consisted first of estimating the total volume of water available for recharge to the upper aquifer upgradient of the landfill. To calculate this volume, it was assumed that the borders of the Garden Creek watershed coincide with the borders of the underlying groundwater zones. Although this assumption may have underestimated total recharge (some groundwater may enter from outside this boundary), the final results of the analysis indicated good agreement between inflow and outflow volumes.

The Garden Creek watershed consists of approximately 668 acres extending north and south of the CLF, as shown on **Figure 30.** Area A of the watershed (**Figure 30**) represents the upgradient area in which groundwater recharge occurs. All groundwater in this area is assumed to flow northward within the confines of the watershed. Area B is the area within which groundwater may be captured in the landfill leachate collection lines and underdrain. The total flow across the south end of the landfill at Section line A (**Figure 30**) should balance the total volume captured in the underdrains plus the total volume of groundwater flow crossing Section line B. This balance is formulated as follows:

Groundwater flow across Section A = underdrain and leachate collection line flow (less internal leachate) + groundwater flow across Section B

Total recharge in Area A was assumed to be the total volume of rainfall less evapotranspiration and surface water runoff. Precipitation data were obtained from the County; rainfall is measured and recorded daily at the CLF. Evapotranspiration was calculated using the Penman equation, and surface water runoff volumes were based on flows measured at the referenced weir locations.

Over the long term (several months), groundwater flow through any section of the watershed equals the amount of groundwater recharge upgradient of that section. Over the short term (days or weeks), groundwater flow equals this recharge less the volume of water temporarily stored in the aquifer during a rise in the water table.

Total flow in the underdrain and leachate lines is represented by total outflow measured at SP-1. As described previously (Section 2.2), flows at SP-1 must be adjusted to remove surface water from the North Pond and landfill cap. Adjusted flows at SP-1 are shown in **Table 3**. Total monthly SP-1 flow volumes were divided by the number of minutes per month to arrive at an average gallons per minute (gpm) value.

Groundwater flow across Section A was estimated on a monthly basis for two dry season months and two wet season months as the sum of flows through the siltstone bedrock, siltstone/till contact, till, and alluvium, minus groundwater storage. Groundwater storage was estimated based on water table rise over the Area A watershed. Flow through each geologic unit was calculated using Darcy's law:

$$Q = K \times i \times A$$

where: Q = groundwater flow (cubic feet per second)
K = hydraulic conductivity of the medium (feet per second)
i = hydraulic gradient (vertical head difference per horizontal distance)
A = effective saturated cross sectional area of the medium

Results of the analysis showed that long-term groundwater flow across Section A was approximately equal to the total volume of recharge given reasonable hydraulic properties for the various geologic deposits. These hydraulic properties and the volumetric results are summarized in **Table 3**. Total outflow across Section B was calculated in the same manner as flow across Section A. The same hydraulic conductivities were used, but cross-sectional areas and hydraulic gradients were different. The results of this analysis are also shown in **Table 3**.

Comparison of the total flow across Section A with the total flow across Section B plus the underdrain flow shows good agreement between the two values. The watershed balance analysis was performed for both the dry season (August and September 1994) and wet season (November and December 1994) for comparison of total SP-1 flows for the same time periods. Results of the watershed balance for both seasons indicate the Garden Creek watershed contains volumes of groundwater flow sufficient to provide the landfill with groundwater inflow equivalent to the volume of water being captured in the leachate collection lines and underdrain.

4.3 LANDFILL HYDROLOGIC BUDGET

4.3.1 Conceptual Model

Various sources provide the water captured in the leachate and underdrain lines. To determine the relative magnitudes of these sources, the landfill was conceptualized as a rectangular box with primary dimensions equal to those of the landfill, as shown on **Figure 31**. Horizontal groundwater inflows to the landfill occur at the south, east, and west faces of the model; upward groundwater inflow (upwelling) occurs at the model floor. Additional water is contributed by internal leachate drainage. This internal source occurs as a results of refuse consolidation over time and delayed drainage of water trapped in the refuse after capping. Outflow from the model occurs at the north face and underdrain and leachate collection system (SP-1).

As stated in Section 3.4, groundwater inflows to the landfill likely originate as:

- groundwater throughflow from upgradient areas
- leakage from Garden Creek
- leakage from east side drainage ditch
- leakage from the South Pond
- leakage through the construction features between the South Pond and the landfill

Flow contributions from each of these sources enter the landfill through one of the faces of the model.

4.3.2 *Analysis*

The hydrologic budget analysis is presented in detail Appendix H, and is summarized below.

The flow inflow/outflow balance was formulated as follows:

inflow: west face + south face + east face + upwelling + cap runoff (directed into SP-1) + internal leachate =
outflow: [underdrain + leachate outflow (SP-1)] + north face

Cap runoff was determined using the County's precipitation data and the Penman equation, as described in the watershed balance discussion. Flow out of the underdrain and leachate lines was converted to gpm based on the County's total monthly SP-1 flow volumes. Flows were calculated for the west, south, east, and north faces based on the properties determined in the watershed balance (Table 3). Sources of flow at these faces are summarized as follows:

- *West Face Contributions* : Groundwater inflow through the west face of the landfill is quantified in two flow regimes: shallow flow in the till and construction fill, and deeper flow in the siltstone.

  Garden Creek contributes to groundwater recharge along the west face and some portion of this likely enters the landfill as groundwater flow. Drainage from the creek was calculated based on maximum loss of flow along the creek measured during high flows at the weirs; maximum calculated loss was approximately 3 gpm. We assume that the portion of infiltrating Garden Creek water that enters the landfill is low relative to groundwater flow across entire west landfill face. Other pathways, such as high permeability construction features, may exist for direct inflow of this water to the landfill; however, no such pathways have been identified.

- *South Face Contributions* : Groundwater at the south face of the landfill flows through the original Garden Creek alluvial channel, till, and siltstone. Hydraulic properties of these units are presented in Table 3. The till and siltstone layers allow markedly less flow due to the relatively low hydraulic conductivities of these units.

As described above, the South Pond and Garden Creek likely contribute to groundwater recharge along the south face. These flows are assumed to enter the landfill as groundwater through the alluvial channel, till, and siltstone. Additionally, construction features may provide conduits between the South Pond and the landfill. Because the extent of these effects are unclear, they are not included in the south face flows.

- *East Face Contributions* : Groundwater movement across the east face of the landfill is quantified identically to the west face, with shallow flow in the till and construction fill, and deeper flow in the siltstone.

  Similar to Garden Creek's contribution to west face flow, some portion of water from the east side drainage ditch likely infiltrates and contributes to groundwater flow across the east face. This contribution to east face inflow is assumed to be minimal due to the low flows observed along the ditch, and the small contribution relative to groundwater flow across the entire east face.

- *North Face Contributions* : The north face of the landfill is partitioned into three groundwater flow regimes similar to the south face of the landfill: the alluvial channel, till, and siltstone.

No flow data exist for internally generated leachate or groundwater upwelling. These values were therefore solved for using the calculated values for flow across each of the faces, calculated cap runoff, and the County's total flow values, as follows:

west face + south face + east face + cap runoff (directed into SP-1) -
[underdrain + leachate outflow (SP-1)] + [north face] =
upwelling + internal leachate

The internally generated leachate volume was set at 5 gpm based on estimated drainage from the refuse area assuming zero precipitation inflow through the cap. Using this value, inflow due to upwelling was determined.

Both wet and dry season flows were evaluated. The dry season was evaluated using SP-1, precipitation, and hydraulic gradient data from August and September 1994, which were the driest months of the year. Dry season flow magnitudes were assumed to represent baseline, or minimum conditions. The wet season was evaluated using data from November and December 1994; these were the most recent and wettest months available at the time of the analysis.

4.3.3 Results

Results of the hydrologic budget for the 1994 dry and wet seasons are summarized in **Table 4** and illustrated in the pie charts shown on **Figure 32.**

Our analysis indicates landfill inflows are ordered, from most to least significant, as follows:

1. Groundwater upwelling
2. South face inflow
3. Internal leachate drainage
4. East face inflow
5. West face inflow

The majority of landfill fluid flow appears to originate as upwelling through the landfill bottom. Inflow through the south landfill face is also significant relative to the other faces, likely due to flow through the alluvium and infiltration from the South Pond. During December 1994, upwelling inflows were calculated to be approximately 69 gpm. The equivalent flux rate for this inflow is approximately 2.5 x 10^{-5} gpm per square foot of landfill floor, based on landfill excavation dimensions of 3,000 feet (length) by 900 feet (width).

This rate likely varies considerably across the landfill, with higher values likely occurring in Stages 1 and 2, where upwelling was observed during construction (see Section 2.1).

4.4 SUMMARY AND CONCLUSIONS

Based on results of the watershed balance and landfill hydrologic budget analyses, we conclude the following:

- The upgradient portion of the Garden Creek watershed provides a sufficient volume of water to account for the calculated inflows to the landfill. Much of the rainfall in the watershed goes into temporary groundwater storage and effectively increases the saturated thickness of the aquifer at each landfill face during the wet season.

- Groundwater upwelling is a significant source of water to the leachate collection and underdrain systems. During the dry season, this inflow is estimated to be a minimum of approximately 6 gpm. Wet season groundwater upwelling (November and December) is estimated to be up to approximately 69 gpm (December), and may be higher during January and February, when total SP-1 flows typically peak.

- Groundwater flow through the alluvial channel at the south face of the landfill also appears to be a significant source. During the dry season, south face groundwater flow is estimated to be approximately 4 gpm; during the wet season, this flow increases to an estimated 14 gpm.

- Groundwater flows across the east and west faces of the landfill section are insignificant relative to the south face and upwelling inflows.

- Internal drainage of leachate may be a significant source of landfill fluids, although it is currently impossible to quantify the volume contributed.

5.0 GROUNDWATER INFLOW MITIGATION ANALYSIS

5.1 INTRODUCTION

This section evaluates technical alternatives to reduce the amount of groundwater that enters the landfill and subsequently requires pretreatment at the pretreatment facility. Mitigation of surface water runoff from the landfill cap is addressed in Section 6.0.

Section 5.2 describes potential groundwater control technologies evaluated for this project. Based on the results of groundwater inflow evaluation described in Section 4.4, the evaluation of alternatives addresses four groundwater-landfill interface boundaries: landfill south face, landfill west face, landfill east face, and groundwater upwelling. Potential alternatives are initially screened with respect to each of these boundaries. Preliminary screening is based on short (1 to 5 years) and long-term effectiveness; implementability, environmental impact, regulatory acceptance, and costs (initial and operation and maintenance [O&M]). The preliminary screening eliminates alternatives that have no merit for groundwater control or are obviously extremely difficult or impossible to construct, and identifies those alternatives most appropriate for each groundwater-landfill interface boundary. After the preliminary screening, a more detailed final evaluation is performed. This evaluation judges the alternatives with respect to three criteria: construction and O&M costs, savings in leachate management costs, and potential for environmental mitigation.

5.2 ALTERNATIVE DESCRIPTIONS AND PRELIMINARY SCREENING

5.2.1 *Introduction*

This section describes the alternatives identified as potentially applicable for mitigating groundwater inflow to the CLF. The alternatives are described conceptually below, in terms of their features and desired effects. The alternatives are then screened, as appropriate, with respect to each of the four groundwater-landfill interface boundaries. Some alternatives apply to more than one boundary, and are considered in combination with others. Alternatives for mitigation of groundwater inflow are described below:

No Action : The no action alternative includes no implementation of mitigation measures to reduce water inflow to the landfill; however, to reduce total costs associated with treatment under the no action alternative, we evaluated two additional options which include purchasing additional disposal capacity. The first option includes doubling the current disposal capacity to allow for eventual Regional Landfill effluent requiring pretreatment; the second includes increasing current disposal capacity approximately 20,000 gallons per day in order to eliminate the need and associated costs for effluent off-hauling and trucking. Costs associated with both options of the no action alternative are included in Table 9. Table 10 is a matrix of costs associated with the second no action alternative.

Line East Ditch : Line east ditch with a geomembrane or low-permeability soil to reduce surface water infiltration into groundwater. The collected water could be discharged downstream of the North Pond or directly into the North Pond. Minor flow diversion would be achieved.

Line Garden Creek : Line Garden Creek along its reach through the landfill with a geomembrane to reduce surface water infiltration. Low-permeability soils could also be used as the lining material. Minor flow diversion would be achieved.

Line South Pond : Construct an impermeable flexible membrane liner at the base of the South Pond to reduce leakage into the southern end of the landfill. There would be construction problems because the bottom of the pond is below the water table, and dewatering would be required during construction and perhaps permanently. Construction would be phased. U.S. Army Corps of Engineers wetland permits would be required.

Interceptor Trench : Excavate an interceptor trench to collect groundwater as it enters the landfill perimeter. Gravity feeding or pumping the collected water to Garden Creek downstream of the North Pond would be required. Trench depths of approximately 20 feet (moderate depth) and 100 feet (deep) are considered. The deep trench would have to be constructed without dewatering to prevent reverse flow of contaminated groundwater. Perforated pipe along the trench bottom and a pump in each 250-foot section between in-trench dams would allow control of the rate of dewatering. The lower ±40 feet of excavation would be in siltstone and would require drilling and blasting prior to rock excavation. It would be difficult and expensive to construct this deep trench, but the potential for interception of groundwater is highest.

Slurry Wall : Excavate a deep trench and fill with a low-permeability bentonite-cement slurry, making a wall to prevent groundwater migration across the boundary. The slurry wall would extend around the upgradient edge and sides of the landfill. There are no naturally occurring impermeable strata to tie the base of this wall into; groundwater would therefore flow under and around the wall. Also, there would be upgradient problems resulting from damming groundwater flow.

Grouting : Inject grout into a series of borings around the upgradient perimeter of the landfill to produce an impermeable wall similar to a slurry wall. Different types of grouting are available, including: compaction, slurry, and chemical. Installation would include drilling borings adjacent to the landfill and grouting under high pressure. Borings would most likely be spaced 3 to 10 feet on center, depending on soil and rock conditions, depth of borings, and grouting pressures.

Inject grout under high pressure beneath the base and sides of the landfill to create a horizontal seal, thus preventing groundwater from entering the landfill. This alternative is considered difficult and costly.

Horizontal/Directional Drilling : Horizontal bore "micro tunnels" below the long axis of landfill to provide drainage for groundwater flow entering the landfill area. Close spacing and long length make the cost very high.

Soil/rock Fracturing : Drill borings in a linear pattern and place inflatable packers in holes. Packers would be inflated and air or water injected at high pressure to fracture soil and rock, creating permeable zones and allowing preferential flow pathways. Use of explosives is also possible. This alternative is considered in combination with deep extraction wells.

Remove Construction Features : Excavate and remove or seal construction features located between the South Pond and the landfill.

Extraction Wells : Install extraction wells at appropriate locations around the landfill to reduce the water table elevation around and under the landfill. This would reduce the volume of groundwater entering the underdrain system and potentially flowing into the landfill through leaks in the bottom liner.

The following sections discuss the specific application of these alternatives to each of the four landfill-groundwater interface boundaries. Tables 5 through 8 summarize the preliminary screening results for each boundary.

5.2.2 *Landfill South Face*

Line Garden Creek Along the South Face of the CLF : Minor flow diversion estimated at 0.2 to 1.0 gpm during the wet season would be achieved. This alternative is being retained for further evaluation and is discussed for the creek as a whole under the final evaluation of mitigation alternatives.

Line South Pond : It is anticipated that wetland soils and plants would have to be stockpiled/stored and re-established in the pond after construction of the liner. The flow diversion is estimated at 1 to 5 gpm during the wet season; however, this diversion varies significantly depending on whether this alternative is implemented alone or in combination with extraction wells or a trench. This alternative is retained for further evaluation.

Interception Trench : Medium depth (±20 feet) and deep (±100 feet) versions are considered:

A medium depth south interceptor trench would range from 10 feet to 30 feet deep. The medium depth trench would intercept groundwater in the alluvium, in the interface between the till and the weathered siltstone, and in any porous lenses in the till. It would be constructed by normal trench construction methods, utilizing a large track-mounted backhoe, trench box shoring, and pumped dewatering. It would intercept most of the estimated 14 gpm south face wet season groundwater flow, but would have little effect on the upwelling groundwater component. The medium depth trench would divert intercepted clean groundwater flow to Garden Creek. This alternative is retained for further evaluation.

A deep interceptor trench would have to be constructed without dewatering to prevent reverse flow of contaminated groundwater. Perforated pipe along the trench bottom and a pump in each 250-foot section between in-trench dams would allow control of the rate of dewatering. The lower 60 to 80 feet of excavation would be in siltstone and require drilling and blasting prior to rock excavation. It would be difficult and expensive to construct a deep trench, but the potential for intercepting groundwater is highest, including all of the 14 gpm south interface and a portion of the 70 gpm upwelling groundwater components. This alternative is retained for further evaluation.

Slurry Wall : In addition to the drawbacks discussed for this alternative in Section 5.2 1, excavation into the siltstone would be very difficult and costly. This alternative is therefore not considered further.

Grouting : Grouting would consist of drilling holes and pressure-injecting grout liquid/slurry into the alluvium, into the interface between the weathered siltstone and the till, and ideally into any porous lenses in the till. This would create a grout wall or curtain. It is not likely this would result in a complete seal/barrier, and some groundwater bypass would probably still occur. Penetration of the grout/sealing liquid into the pores of the siltstone/sandstone is unlikely, even under very high pressures. There are no naturally occurring impermeable strata to tie the base of this grout curtain into (the siltstone is too permeable), and groundwater would flow around and under the grouted area. The cost of this alternative would also be high. This alternative is therefore not considered further.

Horizontal/Directional Drilling : There are two possible applications of this alternative for each of the south, west, and east landfill faces. One application would be angled drilling under the landfill and then pumping out groundwater. This would quickly draw a combination of both clean and contaminated water, actually increasing the contaminated water management volumes and problems. The other application would be to auger 4- to 6-foot-diameter holes along the perimeter of the landfill, and from the bottom of these holes drill horizontally for dewatering or grout injection. This construction would have to be done underwater because dewatering would again draw a combination of clean and contaminated groundwater. Grouting would have the confidence problems described above. In addition, close spacing between borings and long horizontal lengths would make the cost very high. This alternative is therefore not considered further.

Soil/Rock Fracturing : This alternative is considered to have potential for use in combination with deep extraction wells. It is retained for further evaluation.

Remove Construction Features : Several construction features are known to exist that may transport water from the upper groundwater zone south of the landfill across the south landfill face. These features are predominantly conveyance pipes associated with storm water or sewerage and are located beneath the paved landfill perimeter road. Even if these pipes are plugged, gravel bedding and trench disturbance could still allow groundwater seepage through otherwise low permeability material.

It appears those features located between the pond and the landfill were constructed at depths above the water table throughout much of the year (maximum likely depth of approximately 8 feet) and largely run parallel to the perimeter road without penetrating the south landfill face. One feature, a lead from an abandoned catch basin, passes from the landfill under the perimeter road. The catch basin was located just inside the south perimeter of Stage 6 and directed flow to an outfall located in the Garden Creek streambed approximately 60 feet downstream from the South Pond weir. The degree to which this pipe is sealed is not certain.

The magnitude of seepage that results from the construction features is unknown, but is not likely significant in terms of total inflows to the landfill. Because the reduction of inflow due to removal of the construction features can only be speculative, this alternative is not considered further.

Extraction Well Dewatering : This alternative would collect groundwater flowing through the alluvium, the till/weathered siltstone interface, or permeable lenses in the till before it reaches the landfill south face. Deep wells would be installed in a line south of the landfill south face and clean groundwater pumped out to lower the water table to levels below the landfill bottom. Extracted water would be pumped into a header system and discharged to a location in Garden Creek. Care would need to be taken to ensure pumping would not draw contaminated water from beneath the landfill in a reverse flow. To avoid reverse flow, the drawdown would be accomplished slowly, over a period of up to 5 years. The 14 gpm wet season volume of water entering the landfill underdrain system should ultimately be reduced by at least 90 percent. However, construction of the south extraction well dewatering system alone will not significantly reduce upwelling flows. Section 5.2.5 discusses combining extraction wells along the landfill's south, east, and west faces to mitigate upwelling groundwater. Extraction well dewatering is further evaluated for this three-sided configuration.

5.2.3 Landfill West Face

Line Garden Creek Along the West Face of the CLF : This alternative would create a minor flow diversion of approximately 0.8 to 4.0 gpm during the wet season. Lining both the south and west segments of Garden Creek is retained for further evaluation.

Interception Trench : The medium depth (±20 feet) trench evaluated for the south interface is not appropriate along the west face because the alluvium is absent along this face. Only the deep (±100 feet) trench is considered. The potential benefits and drawbacks noted for the deep trench south face application also apply to the west face, including interception of most of the 70 gpm upwelling groundwater component. The deep trench alternative is retained for further evaluation.

Slurry Wall : The drawbacks noted for this alternative under the south face evaluation also apply to the west face. This alternative is therefore not considered further.

Grouting: This alternative would consist of drilling holes and pressure-injecting grout liquid/slurry into the interface between the weathered siltstone and the till, and ideally into any porous lenses in the till. The drawbacks noted for this alternative under the south face evaluation also apply to the west face. This alternative is therefore not considered further.

Horizontal/Directional Drilling : The applications and drawbacks noted for this alternative under the south face evaluation also apply to the west face. This alternative is therefore not considered further.

Soil/Rock Fracturing : The application and potential benefits noted for this alternative under the south face evaluation also apply to the west face. This alternative is therefore not considered further.

Extraction Well Dewatering : This alternative would collect groundwater flowing through the till/weathered siltstone interface and permeable lenses in the till before it reaches the landfill west face. Deep wells would be installed in a line west of the landfill west face and clean groundwater pumped out to lower the water table to levels below the landfill bottom. Similar to the south face application, this groundwater would be extracted slowly over a period of up to 5 years to avoid drawing contaminated water from beneath the landfill. Extracted water would be discharged to Garden Creek. The 0.14 gpm wet season volume of water entering the landfill underdrain system should ultimately be reduced by at least 90 percent. However, construction of the west extraction well dewatering system alone will not significantly reduce upwelling flows. The extraction well alternative is evaluated further in Section 5.2.5 for a combined east, west, and south face configuration.

5.2.4 Landfill East Face

Line the East Ditch : Half-pipes may serve as a barrier to infiltration at a lower cost than geomembrane or low-permeability soil lining. This alternative would create a minor flow diversion of approximately 1 to 5 gpm during the wet season. This alternative is retained for further evaluation.

Interception Trench : As for the west face, the medium depth (±20 feet) trench is not appropriate along the east face because the alluvium is absent. Only the deep (±100 feet) trench is considered. The potential benefits and drawbacks noted previously for the deep trench south and west face applications also apply to the east face. The deep trench alternative is retained for further evaluation.

Slurry Wall : The drawbacks noted for this alternative under the south and west face evaluations also apply to the east face. This alternative is therefore not considered further.

Grout : The drawbacks noted for this alternative under the south and west face evaluations also apply to the east face. This alternative is therefore not considered further.

Horizontal/Directional Drilling : The applications and drawbacks noted for this alternative under the south and west face evaluations also apply to the east face. This alternative is therefore not considered further.

Soil/Rock Fracturing : The application and potential benefits noted for this alternative under the south and west face evaluations also apply to the east face. This alternative is therefore retained for further evaluation.

Extraction Well Dewatering : The application described for this alternative under the south and west face evaluations also applies to the east face. The 0.41 gpm wet season east landfill face groundwater inflow entering the landfill underdrain system would ultimately be reduced by 90 percent. However, construction of the east extraction well system alone will not significantly reduce upwelling flows. As noted under the south and west face evaluations, the extraction well alternative is retained for further evaluation under a combined east, west, and south face configuration.

5.2.5 Groundwater Upwelling

Interception Trench : The medium depth (±20 feet) trench is not appropriate for intercepting the upwelling groundwater component because the trench would not be deep enough. Only a three-sided configuration (south, west, and east landfill faces) of the deep (±100 feet) trench is considered adequate to intercept enough groundwater to lower the water table beneath the landfill. Deep trench design and potential construction difficulties would be as described under the south face evaluation. Potential groundwater interception includes most of the wet season 70 gpm upwelling component and all of the wet season 14 gpm south face alluvium component. This deep trench configuration is retained for further evaluation.

Slurry Wall : The drawbacks noted for this alternative under the south, west, and east face evaluations also apply to the upwelling component. This alternative is therefore not considered further.

Grouting : Grout undersealing could be used to reduce permeability of the landfill bottom. Given the complexity of the surface cap and gas collection system, it is probably not wise to drill through the landfill surface. Drilling through the bottom liner would add even more potential leak points. Even if borehole seals at liner drainage layers could be guaranteed, as many as a thousand holes would be needed for adequate grouting. Therefore, installation procedures would include directional drilling of borings from the north under the landfill and grouting under high pressure. Construction under the landfill would be extremely expensive due to the large number and length of boreholes. A huge volume of grout liquid/slurry could be injected into drainage layers and/or porous soils without confidence in a complete seal/barrier, and some bypass through the grout would still be likely. In addition, penetration of the grout/sealing liquid into the pores of the sandstone/siltstone is unlikely, even under very high pressures. Because of these potential drawbacks, this alternative is not considered further.

Horizontal/Directional Drilling : The applications and drawbacks noted for this alternative under the south, west, and east face evaluations also apply to the upwelling component. This alternative is therefore not considered further.

Soil/Rock Fracturing : The application and potential benefits noted for this alternative under the south, west, and east face evaluations also apply to the upwelling component. This alternative is therefore retained for further evaluation.

Extraction Well Dewatering : Deep groundwater extraction wells would be installed along the south, west, and east faces of the landfill. Clean groundwater would be extracted to lower the water table to levels below the landfill bottom. As described for the previous evaluations, this groundwater would be extracted slowly over a period of up to 5 years to avoid drawing contaminated water from beneath the landfill. Extracted water would be discharged to Garden Creek downstream from the North Pond. The volume of water entering the landfill underdrain system would ultimately be reduced by 90 percent or better. Recharge of water into the interior of the landfill through liner leaks would also be eliminated, resulting ultimately in near-elimination of leachate discharge.

5.3 FINAL EVALUATION OF ALTERNATIVES

5.3.1 Approach

This section further evaluates those alternatives that passed the preliminary screening summarized in Section 5.2. The final evaluation is organized by alternative; for each alternative, only those groundwater-landfill interface boundaries for which the alternative has potential application are considered.

Two primary criteria were used to evaluate the alternatives:

- ***Performance*** is the likelihood that the completed alternative will meet its goals, and is an estimate of the amount of groundwater prevented from requiring management as contaminated water (i.e., avoided leachate flow rate). This avoided flow rate is converted into an annual avoided volume and an annual avoided cost in dollars, and then into present value of avoided cost for 30 and 50 years.

- ***Costs*** are estimated based on information from contractors and suppliers, cost tables, and our experience with similar projects. Where there is uncertainty, the most likely costs are selected after consideration of a range of possible low to high costs. Cost figures are typically expressed in units of measure (e.g., linear feet of trench at $/lf) and total costs. Anticipated construction issues and costs associated with design, permitting, etc. are included.

  The construction/O&M costs and avoided costs for each alternative are calculated based on rough estimates and assumed groundwater flows. Actual costs could be 35 percent higher or 50 percent lower than the values used for each mitigation alternative.

  Costs are also developed for the No Action alternative, and include leachate disposal fees, County personnel labor, power, equipment maintenance and repair, supplies, and chemical analysis. Appendix I provides detailed present value cost breakdowns for each alternative.

  Table 9 summarizes the cost analysis for each alternative. The 30- and 50-year present values are calculated based on estimated initial (construction) and O&M costs for each alternative. A net present cost is then listed, which for each alternative represents the present value of all expenditures. This net present cost includes construction and O&M costs, plus the No Action costs, minus the avoided costs. Cost effectiveness is judged for each alternative by comparing the 30- and 50-year present values to the associated avoided costs.

In addition to these criteria, the alternatives were considered in terms of their potential to mitigate landfill-related impacts on groundwater.

5.3.2 *Alternative Evaluation*

Line Garden Creek : There appears to be no advantage to lining only the south or west segment of Garden Creek; therefore, lining both segments is the alternative receiving final evaluation. Liner materials were evaluated for appropriateness. Low-permeability soils were eliminated because of the potential difficulty in placing and maintaining them on the relatively steep (1-1/2:1) creek side-slopes. Half-pipes were eliminated because surface water flow tends to erode adjacent soil and run under half-pipes, especially during and after extreme storm events. 80-mil textured HDPE is therefore the only liner option evaluated.

Preparation would include clearing and grubbing 8 feet beyond the top of the creek slopes, removing the existing quarry spalls, smoothing the side-slopes, installing a drainage blanket and perforated pipe, and excavating an anchor trench. The liner and protective geotextile would be placed, then covered with a blanket of small crushed rock and then 2- to 4-inch crushed rock. The flow channel would have the quarry spalls replaced for protection against erosion. The difficulty would be in placing materials on the steep side-slopes. Widening the creek channel to lessen the slope steepness would require massive excavation of the high slope west of the creek and would be even more expensive. The cost of design, construction, and construction administration is estimated at $1,090,000, and the 30- and 50-year present values are estimated at $1,247,900 and $1,248,000, respectively.

Present infiltration from Garden Creek into groundwater is estimated at 3 to 5 gpm during the wet season to none during the dry season. The average annual infiltration rate is estimated at about 1.6 gpm, and total annual infiltration is estimated at about 840,000 gallons/year. Lining the creek would likely be effective in eliminating this infiltration; however, roughly half that portion of the groundwater now bypasses the landfill underdrain system, so the avoided leachate flow if the creek were lined would be only 50 percent of 840,000 gallons/year, or 420,000 gallons/year. The potential annual savings of that avoided flow is $3,750, and the 30- and 50-year present values of that savings are $31,900 and $33,100, respectively. Comparing these values with the costs above indicates this alternative would not be cost effective.

There would be no advantage to installing this liner in combination with the deep trench or the extraction well dewatering alternatives. Those alternatives would be installed between Garden Creek and the landfill, and would intercept the creek infiltration. Lining Garden Creek would have additive benefits in combination with lining the South Pond and the east ditch, but would not improve the overall cost effectiveness of these alternatives.

This alternative would have no significant beneficial impact on landfill-related contamination in groundwater.

Line the South Stormwater Detention Pond: Liner materials were evaluated for appropriateness. A liner consisting of low-permeability soils would be difficult to construct because the pond is an expression of the water table. Low-permeability soils would probably be more expensive to use in construction than a flexible membrane, and would still allow infiltration. 80-mil textured HDPE is therefore the only liner option evaluated.

There would be considerable pre-design work associated with obtaining hydraulic and wetland permits. Construction preparation would include dewatering, carefully removing and stockpiling the wetland plants and soils from the area to be lined, smoothing the side-slopes, installing a drainage blanket and perf-pipe, and excavating a perimeter anchor trench. The liner and protective geotextile would be placed, then covered with the stockpiled soils, and the wetland plants reestablished. A permanent dewatering system, with pumps and emergency power generator, would be installed. The inlet and outlet flow channels would have quarry spalls placed for erosion protection. The cost of permitting, design, construction, and construction administration is estimated at $863,000, and the 30- and 50-year present values are $975,500 and $976,200, respectively.

Present infiltration from the South Pond into groundwater is estimated at 3 to 5 gpm during the wet season. The average annual average infiltration rate is estimated at about 1.6 gpm, and total annual infiltration is estimated at about 840,000 gallons/year. Lining the pond would be effective in eliminating this infiltration. Nearly all of that portion of the groundwater now is collected by the landfill underdrain system, so the avoided leachate flow if the pond were lined would be 840,000 gallons/year. The potential annual savings of that avoided flow is $7,500, and the 30- and 50-year present values of that savings are $63,800 and $66,200, respectively. Comparing these values with the costs above indicates this alternative would not be cost effective.

There would be no advantage to installing this liner in combination with the deep trench or the extraction well dewatering alternatives. Those alternatives would be installed between the pond and the landfill, and would intercept the pond infiltration. Lining the South Pond would have additive benefits in combination with lining Garden Creek and the east ditch, but would not improve the overall cost effectiveness of these alternatives.

This alternative would have no significant beneficial impact on landfill-related contamination in groundwater.

Line the East Ditch : Liner materials were evaluated for appropriateness. Low-permeability soils were eliminated because they would be more expensive than a flexible membrane and would still allow some infiltration. Half-pipes were eliminated because surface water flow tends to erode adjacent soil and run under half-pipes, especially during and after extreme storm events. 80-mil textured HDPE is therefore the only liner option evaluated.

Preparation would include clearing vegetation, smoothing the side-slopes, installing a drainage blanket and perf-pipe, and excavating anchor trenches. The liner and protective geotextile would be placed, then covered with a blanket of small crushed rock and then 2- to 4-inch crushed rock. The immediate flow channel would have quarry spalls placed to protect against erosion. The cost of design, construction, and construction administration is estimated at $368,000, and the 30- and 50-year present values are $422,300 and $422,700, respectively.

Present infiltration from the east ditch into groundwater is estimated at 0 to 3 gpm during the wet season to none during the dry season. The average annual infiltration rate is estimated at about 1.0 gpm, and total annual infiltration is estimated at about 525,000 gallons/year. Lining the east ditch would likely be effective in eliminating this infiltration. Nearly all of that portion of the groundwater is collected by the landfill underdrain system because the ditch is adjacent to the landfill liner; therefore, the avoided leachate flow if the east ditch were lined would be 525,000 gallons/year. The potential annual savings of that avoided flow is $4,500, and the 30- and 50-year present values of that savings are $38,300 and $39,700, respectively. Comparing these values with the costs above indicates this alternative would not be cost effective.

There could be a small increase in avoided leachate flow by installing this liner in combination with the deep interceptor trench or the extraction well dewatering alternatives. These alternatives would be installed farther away from the landfill than the east ditch, and would not intercept the ditch infiltration. Lining the east ditch would have additive benefits in combination with lining the South Pond and Garden Creek, but would not improve the overall cost effectiveness of these alternatives.

This alternative would have only a minor beneficial impact on landfill-related contamination in groundwater, alone or in combination with other alternatives.

Medium Depth Interceptor Trench - South Face : The south face medium depth interceptor trench would range from 10 feet to 30 feet deep, with an average depth of 20 feet. It would be constructed by normal trench construction methods, utilizing a large track-mounted backhoe, trench box shoring, and pumped dewatering. Rapid dewatering would not cause reverse flow of contaminated groundwater. The clean groundwater intercepted by this trench would be pumped to Garden Creek. The cost of design, construction, and construction administration is estimated at $2,574,000, and the 30- and 50-year present values are $2,917,000 and $2,918,000, respectively.

The medium depth trench would intercept most of the estimated 14 gpm south interface wet-season groundwater flow in the alluvium, in the interface between the weathered siltstone and the till, and in any porous lenses in the till. The average annual infiltration rate is estimated at 6.5 gpm, and total annual infiltration is estimated at 3,410,000 gallons/year. Constructing the medium depth trench would likely be effective in eliminating this infiltration. Nearly all of this groundwater flow is currently collected by the landfill underdrain system because the flow travels directly to the liner;

therefore, the avoided leachate flow if the medium trench were constructed would be 3,410,000 gallons per year. The potential annual savings of that avoided flow is $30,000, and the 30- and 50-year present values of that savings are $255,000 and $265,000, respectively. Comparing these values with the costs above indicates this alternative would not be cost effective.

There could be a small increase in groundwater capture by constructing the medium depth trench in combination with lining the South Pond and Garden Creek. The construction and O&M costs would be additive, but there would only be a small increase in avoided leachate flows in those combinations. The pond and creek liners would be installed farther away from the landfill than the medium trench, and would eliminate a different component of groundwater flow.

Lining the east ditch would have additive benefits. There would be no advantage to constructing the medium trench in combination with the deep trench or the extraction wells.

This alternative would have only a minor beneficial impact on landfill-related contamination in groundwater, alone or in combination with other alternatives.

Deep Interceptor Trench : Before designing the deep interceptor trench, a comprehensive hydrogeologic model would have to be developed for an area about 1/2 mile around the landfill perimeter. This model would allow more accurate determination of adequate trench depths. The trench must be deep enough to lower the water table to a few feet below the landfill underdrain system. If the trench were too shallow, this fact would not be known until the gradual drawdown was complete and the trench would have to be reconstructed. Excavating the trench deeper than necessary would also create a large additional cost.

The model would also be used to predict dewatering impacts on the water table at domestic water supply wells in the CLF vicinity. Model development would likely require installation of approximately 10 monitoring wells/piezometers, a data search of agency and well owner files, installation of water table transducers and recorders in existing and new wells, setup of the model on computer, and calibration of the model.

The deep trench would have to be constructed without dewatering to prevent reverse flow of contaminated groundwater. Perforated pipe along the trench bottom and a pump in each 250-foot section between in-trench dams would allow control of the rate of dewatering. The lower ±40 feet of excavation would be in siltstone and would require drilling and blasting prior to rock excavation. It would be very difficult and expensive to construct this trench, but the potential for interception of groundwater is highest, including the interception of all of the south face groundwater inflow and most, if not all, of the upwelling groundwater component. The clean groundwater intercepted by this deep trench would be pumped to Garden Creek. The cost of hydrogeologic modeling, design, construction, and construction administration is estimated at $30,406,000, and the 30- and 50-year present values are $34,228,000 and $34,233,000, respectively.

The deep trench would nearly eliminate the groundwater currently collected by the landfill underdrain and leachate collection systems. These systems now collect estimated wet season flows of 14 gpm from the south landfill-groundwater interface and 70 gpm from the upwelling component. The average annual flow from these two inflow components is estimated at 59 gpm, and total annual flow is estimated at 31,000,000 gallons/year. The avoided leachate flow if the deep trench were constructed would therefore be 31,000,000 gallons/year. The potential annual savings of that avoided flow is $270,000, and the 30- and 50-year present values of that savings are $1,660,000 and $1,745,000, respectively. Comparing these values with the costs above indicates this alternative would not be cost effective in terms of avoided leachate management costs.

There could be a small increase in groundwater capture by constructing a deep trench in combination with lining the east ditch because the ditch would collect water immediately next to the landfill liner. Cost effectiveness would not be improved by this combination. There would be no advantage to constructing the deep trench in combination with lining the South Pond and Garden Creek because the deep trench would intercept infiltration from the creek and the pond. There would be no advantage to constructing the deep trench in combination with the medium trench or the extraction wells.

The deep interceptor trench alternative could have a significant beneficial impact on landfill-related contamination in groundwater by eliminating most of the recharge to the contaminated zone. Additional benefits could then be achieved with much better results by pumping and treating contaminated groundwater.

Extraction Wells With Rock Fracturing: Before beginning a design to install extraction wells with rock fracturing, a comprehensive hydrogeologic model would have to be developed as described above for the deep interceptor trench evaluation. The model would allow more accurate determination of adequate well depths (i.e., to lower the water table to a few feet below the landfill underdrain system) and predict dewatering impacts on the local water table.

Installation of a row of extraction wells was recognized in the preliminary screening as a possible solution to intercepting most of the groundwater upwelling component. Deep wells would be installed along the landfill's south, west, and east faces. Clean groundwater would be pumped into a header system that would discharge to Garden Creek downstream from the North Pond.

An initial evaluation shows that due to the lower permeabilities of the till and siltstone, the well spacing would need to be roughly 10 feet. However, by combining this alternative with rock fracturing, it appears the spacing can be increased to 20 to 25 feet, and pumps can be installed in every other well. The rock fracturing technique involves sliding hole-seals, called packers, down the well boreholes at about 20-foot centers. Each space between packers is individually charged with water at up to 3,500 pounds per square inch (psi) to develop cracks away from the hole. This process is called hydro-fracturing. A hydro-fracturing trial run would need to be made in a few holes to verify spacing. The drawdown characteristics of each well would be improved using this technique.

It would be expensive to construct this extraction well/rock fracturing system. However, the potential for interception of groundwater is high, similar to the deep trench, including all of the south interface inflow and most, if not all, of the upwelling component. This alternative would have to be constructed with minimal dewatering to prevent reverse flow of contaminated groundwater. The drawdown would be accomplished gradually over a period of approximately 5 years. The cost of hydrogeologic modeling, design, construction, and construction administration is estimated at $8,042,000, and the 30- and 50-year present values are $9,414,000 and $9,429,000, respectively.

This alternative would nearly eliminate the groundwater currently collected by the landfill underdrain and leachate collection systems. These systems now collect estimated wet season flows of 14 gpm from the south landfill-groundwater interface and 70 gpm from the upwelling component. The average annual flow from these two inflow components is estimated at 59 gpm, and total annual flow is estimated at 31,000,000 gallons/year. The avoided leachate flow if the extraction well/rock fracturing alternative were constructed would therefore be 31,000,000 gallons/year. The potential annual savings of that avoided flow is $270,000, and the 30- and 50-year present values of that savings are $1,660,000 and $1,745,000, respectively. Comparing these values with the costs above indicates this alternative would not be cost effective in terms of avoided leachate management costs.

There could be a small increase in groundwater capture by constructing this alternative in combination with lining the east ditch because the ditch would collect water immediately next to the landfill liner. Cost effectiveness would not be improved by this combination. There would be no advantage to installing extraction wells in combination with lining the South Pond and Garden Creek because the wells would intercept infiltration from the creek and the pond. There would be no advantage to installing the extraction wells in combination with either the medium or deep trench.

The extraction well/rock fracture alternative could have a significant beneficial impact on landfill-related contamination in groundwater by eliminating most, if not all, of the recharge to the contaminated zone. Additional benefits could then be achieved with much better results by pumping and treating contaminated groundwater.

6.0 SURFACE WATER MITIGATION ANALYSIS

6.1 INTRODUCTION

This section discusses alternatives for reducing the volume of landfill cap surface water runoff subject to treatment. Reducing this volume depends on mitigating water quality parameters to levels at or below Garden Creek discharge action levels.

The elevated conductivity is likely due to a combination of sulfate, calcium, magnesium, and carbonates in the water draining from the cap soils. The sulfate identified in the analysis is possibly from the use of sulfate of ammonia, an inexpensive fertilizer with a high nitrogen yield, which may have been mixed with the compost during hydroseeding. The source of carbonate identified in the analysis is possibly carbon dioxide, released by the aerobic decomposition of the compost mixed in the topsoil. This carbonate would leach calcium and magnesium from the cap soil. There is probably some increase in mineral solubility from the cap soil due to the heat generated by refuse decomposition within the landfill, which could increase conductivity.

Potential surface water runoff mitigation alternatives are described in the following paragraphs.

6.2 MITIGATION ALTERNATIVES

Continue the Present Discharge Practice: Conductivity, sulfate, and hardness declined considerably since the cap was placed. This decline tends to indicate a one-time source that is being flushed from the cap soils by precipitation. Given this decline, discharge to the North Pond or Garden Creek as much as possible remains a viable alternative.

Construct a Separate Stormwater Detention Pond for Cap Runoff: A detention pond may be appropriate if cap discharge to the creek is allowed at all times. This would prevent further contamination of cap runoff by contaminated groundwater, and facilitate discharge to the creek. Necessary storage capacity would need to be evaluated with respect to available space.

Obtain a Regulatory Variance for Garden Creek Discharge : Apply for a variance to discharge surface water having conductivity, sulfate, and/or hardness exceeding action levels to Garden Creek. If necessary, this application could be supported by the results of a screening level environmental risk assessment.

Treat Cap Runoff: Cap runoff could continue to be treated in the on-site pretreatment facility and discharged with leachate to a publicly-owned treatment works (POTW). The pretreatment/ POTW system is intended for a much higher concentration of contaminants, and is inherently a more expensive treatment than necessary.

Other options include filtration/ion exchange, consisting of running the water through a deep bed sand filter and then through an ion exchange system. The ion exchange would be similar to an industrial ion exchange/water softening system. The system could include equalization ponds and large ion-exchange units. Facility costs would range from $20,000 to $30,000. Maintenance and salt replenishment in the ion-exchange units would be required, costing around $4,000 per year. Vendors suggest that filtration/ion exchange alone may be sufficient to reduce the conductivity from 850 umhos/cm to less than 700 umhos/cm. Pilot testing is recommended to verify this performance.

If the filtration/ion exchange system does not adequately reduce conductivity, an additional de-ionization unit would be required. De-ionization units contain anionic and cationic exchange resins and either mixed-bed or dual-bed processes. The additional cost could be $20,000. O&M, including maintenance and resin regeneration, would cost $10,000 per year. Trailer- or skid-mounted systems of this nature are also available on a lease or rental basis.

Reverse osmosis units would perform the needed cleanup, but are very expensive on a unit-cost basis.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 GROUNDWATER INFLOW

None of the evaluated mitigation alternatives is cost effective in terms of reducing leachate management costs. Of the two alternatives that would be most successful in reducing leachate pretreatment volumes (deep trench and extraction wells/rock fracturing), the extraction wells/rock fracturing alternative has the lower net present cost ($10,306,000). This alternative also has the lower ratio (5.7:1) of present value of costs:present value of avoided costs; hence, its cost per gallon of avoided leachate would be lowest. This alternative also appears to have the greatest potential for supplemental groundwater control, if needed for cleanup of landfill-related groundwater contamination.

Lining the east ditch has the lowest overall net present cost, but has a high ratio (11.0) of present value of costs:present value of avoided costs. Hence, it would have a high cost per gallon of avoided leachate, and would only intercept 1.5 percent of the leachate.

Actual flows within each landfill interface analyzed could also vary by up to 2 to 5 times the values used. However, the possible total avoided cost is based on actual flows from the underdrain and leachate systems and should be fairly accurate. Considering this while reviewing the present worth information in Table 9, it is apparent that the costs of each alternative will still considerably exceed the avoided costs, even if actual values are at the maximum deviation.

We recommend the no action alternative be implemented unless unforeseen events significantly change the values in the cost analysis. However, diversion of the landfill cap runoff from the pretreatment facility should be continued to the fullest extent possible to minimize total leachate management costs. We further recommend the County purchase 20,000 gallons per day additional disposal capacity to convey effluent that is currently off-hauled and trucked to the City of Everett. Costs associated with this option under the no action alternative are the lowest in terms of net present value of the alternatives considered in our evaluation.

7.2 SURFACE WATER

By far the most cost-effective alternative is to continue to discharge cap runoff through the North Pond to Garden Creek as much as possible. If and when that is not possible, we recommend applying for a permit variance, with the possible support of an environmental risk assessment if necessary. An internal review of cap runoff discharge procedures could help determine when and if it might be necessary to begin the application process. If that process is not successful, it would be cost effective to develop the filtration/ion exchange and de-ionization alternative on a lease or rental basis, and continue to discharge through the North Pond to Garden Creek. A new, separate stormwater detention pond may facilitate implementation of either a variance or treatment.

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10 Copies

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Quality Assurance/Technical Review by:

Susan J. Penoyar, P.E.
Associate Engineer

TMM/CNM/jlh

Table 1
Garden Creek Flow Data from Weirs

Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Date	Weir I.D.						
	WR-1	WR-2	WR-3	WR-4	WR-5	WR-6	Pond
	gpm						
10/31/94	0.62	0.62	0.36	0.62	0.24	N/A	N/A
11/08/94	3.74	2.01	1.44	2.17	1.25	0.03	14.24
11/23/94	23.82	21.80	18.66	21.80	N/A	N/A	49.23
11/28/94	8.90	7.44	6.14	8.52	5.59	0.00	18.69
12/13/94	8.90	7.10	6.14	7.44	5.14	0.00	N/A
12/19/94	Flood Conditions						

Notes:

gpm – Gallons per minute.
N/A – Not available.

Table 2
Garden Creek Discharge Action Levels and December 1993 Chemistry Data
Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Parameter	Action Level	L-1 Data (Sampled December 1993)
Temperature [a]		
Chloride	230 mg/L	5.7
Specific Conductance	700 µmhos/cm	850
pH	6.5 < pH < 8.5	
Hardness	N/A	400
Turbidity [b]		3.5 NTU
Biochemical Oxygen Demand		<10
Sulfate	250 mg/L	270
Ammonia [c]		0.065
Nitrate	N/A	0.72 *
Nitrite	N/A	0.012
Fecal Coliform	100 organisms/100 mL	
TOC	N/A	<1
Total Metals		
Arsenic (As)	190 µg/L	0.002 mg/L
Cadmium (Cd) [d]		<0.002 mg/L
Chromium (Cr)	11.0 µg/L	<0.006 mg/L
Copper (Cu) [e]		0.018 mg/L
Iron (Fe)	N/A	0.93 mg/L
Lead (Pb) [f]		<0.001 mg/L
Mercury (Hg)	0.012 µg/L	<0.0002 mg/L
Nickel (Ni) [g]		0.02 mg/L
Silver (Ag)	0.12 µg/L	<0.01 mg/L
Zinc (Zn) [h]		0.015 mg/L

Notes:

*Nitriate + nitrite nitrogen.
a) Use formula WAC 173-203-030 (2)(c)(iv).
b) Use formula WAC 173-203-030 (2)(c)(iv).
c) Use formula WAC 173-203-040 (3)(g).
d) Use formula WAC 173-203-040 (3)(j).
e) Use formula WAC 173-203-040 (3)(p).
f) Use formula WAC 173-203-040 (3)(r).
g) Use formula WAC 173-203-040 (3)(u).
h) Use formula WAC 173-203-040 (3)(bb).
mg/L - Milligrams per liter.
N/A - Data not available.
NTU - Nephelometric turbidity unit.
µmhos/cm - Micromhos per centimeter.
µg/L - Micrograms per liter.

Table 3
Watershed Balance Results
Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Parameter	Results			
Groundwater Flow Parameters – Area A	$K_{till/fill}$	1×10^{-5} cm/s	$i_{till/fill}$	0.07
	$K_{alluvium}$	1×10^{-1} cm/s	$i_{alluvium}$	0.1
	$K_{bedrock}$	1×10^{-5} cm/s	$i_{bedrock}$	0.04
	$K_{fracture}$*	1×10^{-1} cm/s	$i_{fracture}$	0.07
Groundwater Flow Parameters – Area B	$K_{till/fill}$	1×10^{-5} cm/s	$i_{till/fill}$	0.07
	$K_{alluvium}$	1×10^{-1} cm/s	$i_{alluvium}$	0.1
	$K_{bedrock}$	1×10^{-5} cm/s	$i_{bedrock}$	0.04
Inflow		**Dry Season**	**Wet Season**	
Total Flow Across Section A		20 gpm	144 gpm	
Outflow				
Total Flow Across Section B		8 gpm	65 gpm	
Underdrain and Leachate Collection System (SP–1)		12 gpm	79 gpm	

Notes:

*Fracture – Weathered siltstone/till interface.
cm/s – Centimeters per second.
gpm – Gallons per minute.
i – Hydraulic gradient.
K – Hydraulic conductivity.
Dry season – August/September 1994.
Wet Season – November/December 1994.

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Table 4
Landfill Hydrologic Budget Analysis Results
Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

	August	September	November	December
Rainfall (inches)	0.25	2	8	11
Inflows (gpm)				
Face/Source				
South	4	4	14	14
West	0.11	0.12	0.38	0.41
West	0.11	0.11	0.13	0.14
GW Upwelling	16	6	34	69
Internal Leachate	5	5	5	5
Total Inflow (gpm)	25	15	54	89
Outflows (gpm)				
Face/Source				
North	3	3	9	10
Adjusted SP-1 *	23	12	45	79
Total Outflow	25	15	54	89

Notes:

*SP-1 flows adjusted to reflect only flow values from the underdrain and leachate line.
gpm – Gallons per minute.

Table 5
Groundwater Inflow Mitigation Alternatives: South Face of Landfill
Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

COST ($)	LOW	MOD.	HIGH
IMPLEMENT DIFFICULTY	EASY	MOD.	DIFF.
	●	◒	○
EFFECT	GOOD	FAIR	POOR
ADD. BENEFITS	YES	LIM.	NONE

ALTERNATIVE	COMMENTS	EVALUATION CRITERIA						ADDITIONAL EVALUATION
		DESIGN AND CONSTRUCTION COSTS	OPERATION AND MAINTENANCE COSTS	SHORT-TERM (1-5 yrs) EFFECTIVENESS	LONG-TERM EFFECTIVENESS	IMPLEMENTATION DIFFICULTY	ADDED BENEFITS (Mitigate Contaminated Groundwater)	
No Action	Continue to treat water as currently handled.	●	○	○	○	●	○	YES
Line Garden Creek along south reach	Effect will be minor.	●	●	◒	◒	◒	○	YES
Line South Pond	Lining pond will reduce infiltration into groundwater.	●	●	◒	◒	◒	◒	YES
Interceptor Trench (Medium and Deep)	High cost/benefit ratio. May have to pump water from trench. Deep trench construction problems and high costs.	○	◒	●	●	○	◒	YES
Slurry Wall	Should reduce groundwater inflows into landfill from Garden Creek watershed. No impermeable base to prevent bypass.	○	◒	○	○	○	◒	NO
Grouting	Most likely would not alter groundwater flow sufficiently.	○	◒	○	○	○	○	NO
Horizontal/Directional Drilling	May be effective but at high cost. Precautions needed to avoid further contamination of groundwater.	○	◒	◒	◒	○	◒	NO
Soil/Rock Fracturing	Precautions needed to avoid further contamination of groundwater. Used in combination with extraction wells.	○	◒	○	◒	○	◒	YES
Remove Construction Features	Remove culvert installed to drain Stage 6 into south detention pond.	●	●	○	○	●	○	NO
Extraction Wells	Effective but high initial costs and high O&M costs. Evaluate combined south, west, and east face wells.	○	○	●	●	◒	◒	YES

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Table 6
Groundwater Inflow Mitigtion Alternatives: West Face of Landfill

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

COST ($)	LOW	MOD.	HIGH
IMPLEMENT DIFFICULTY	EASY	MOD.	DIFF.
	●	◒	○
EFFECT	GOOD	FAIR	POOR
ADD. BENEFITS	YES	LIM.	NONE

ALTERNATIVE	COMMENTS	EVALUATION CRITERIA						
		DESIGN AND CONSTRUCTION COSTS	OPERATION AND MAINTENANCE COSTS	SHORT-TERM (1-5 yrs) EFFECTIVENESS	LONG-TERM EFFECTIVENESS	IMPLEMENTATION DIFFICULTY	ADDED BENEFITS (Mitigate Contaminated Groundwater)	ADDITIONAL EVALUATION
No Action	Continue to treat water as currently handled. Significant loss from Garden Creek only occurs during high flow conditions.	●	○	○	○	●	○	YES
Line Garden Creek	Lining Garden Creek will reduce infiltration into groundwater. Effect will be minor except during the wet season.	●	●	◒	◒	◒	○	YES
Interceptor Trench (Deep only)	High cost/benefit ratio. May have to pump water from trench. Deep trench construction problems and high costs.	○	◒	●	●	○	◒	YES
Slurry Wall	Not a viable alternative along west side of landfill due to no impermeable base to prevent bypass.	○	◒	○	○	○	◒	NO
Grouting	Most likely would not alter groundwater flow sufficiently.	○	◒	○	○	○	○	NO
Horizontal/Directional Drilling	May be effective but at high cost. Precautions needed to avoid further contamination of groundwater.	○	◒	◒	◒	○	◒	NO
Soil/Rock Fracturing	Precautions needed to avoid further contamination of groundwater. Used in combination with extraction wells.	○	◒	◒	◒	○	◒	YES
Extraction Wells	Effective but high initial costs and high O&M costs. Evaluate combined south, west, and east face wells.	○	○	●	●	◒	◒	YES

Table 7
Groundwater Inflow Mitigation Alternaties: East Face of Landfill
Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

COST ($)	LOW	MOD.	HIGH
IMPLEMENT DIFFICULTY	EASY	MOD.	DIFF.
	●	◒	○
EFFECT	GOOD	FAIR	POOR
ADD. BENEFITS	YES	LIM.	NONE

ALTERNATIVE	COMMENTS	EVALUATION CRITERIA						ADDITIONAL EVALUATION
		DESIGN AND CONSTRUCTION COSTS	OPERATION AND MAINTENANCE COSTS	SHORT-TERM (1-5 yrs) EFFECTIVENESS	LONG-TERM EFFECTIVENESS	IMPLEMENTATION DIFFICULTY	ADDED BENEFITS (Mitigate Contaminated Groundwater)	
No Action	Allow ditch flow to continue unaltered.	●	○	○	○	●	○	YES
Line East Ditch	Lining ditch will reduce infiltration into groundwater. Effect in reducing groundwater flow will be minor.	◒	●	◒	◒	●	○	YES
Interceptor Trench (Deep only)	High cost/benefit ratio. May have to pump water from trench. Deep trench construction problems and high costs.	○	◒	●	●	○	◒	YES
Slurry Wall	Not a viable alternative along east side of landfill due to no impermeable base to prevent bypass.	○	◒	○	○	○	◒	NO
Grouting	Most likely would not alter groundwater flow sufficiently.	○	◒	◒	◒	○	◒	NO
Horizontal/Directional Drilling	May be effective but at high cost. Precautions needed to avoid further contamination of groundwater.	○	◒	◒	◒	○	◒	NO
Soil/Rock Fracturing	Precautions needed to avoid further contamination of groundwater. Used in combination with extraction wells.	○	◒	◒	◒	○	◒	YES
Extraction Wells	Effective but high initial costs and high O&M costs. Evaluate combined south, west, and east face wells.	○	○	●	●	○	◒	YES

Table 8

Groundwater Inflow Mitigation Alternatives: Groundwater Upwelling

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

COST ($)	LOW	MOD.	HIGH
IMPLEMENT DIFFICULTY	EASY	MOD.	DIFF.
	●	◒	○
EFFECT	GOOD	FAIR	POOR
ADD. BENEFITS	YES	LIM.	NONE

		EVALUATION CRITERIA						
ALTERNATIVE	COMMENTS	DESIGN AND CONSTRUCTION COSTS	OPERATION AND MAINTENANCE COSTS	SHORT-TERM (1-5 yrs) EFFECTIVENESS	LONG-TERM EFFECTIVENESS	IMPLEMENTATION DIFFICULTY	ADDED BENEFITS (Mitigate Contaminated Groundwater)	ADDITIONAL EVALUATION
No Action	Continue to treat water as currently handled.	●	○	○	○	●	○	YES
Interceptor Trench (Deep only)	High cost/benefit ratio. May have to pump water from trench. Deep trench construction problems and high costs.	○	◒	●	●	○	◒	YES
Slurry Wall	No impermeable base to prevent bypass.	○	◒	○	○	○	◒	NO
Grouting	Most likely would not alter groundwater flow sufficiently.	○	◒	○	○	○	○	NO
Horizontal/Directional Drilling	May be effective but at high cost. Precautions needed to avoid further contamination.	○	◒	◒	◒	○	◒	NO
Soil/Rock Fracturing	Precautions needed to avoid further contamination of groundwater. Used in combination with extraction wells.	○	◒	○	◒	○	◒	YES
Extraction Wells	Effective but high initial costs and high O&M costs. Evaluate combined south, west, and east face wells.	○	○	●	●	○	◒	YES

Table 9
Cost Analysis – Groundwater Inflow Mitigation Alternatives

Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Alternative	Estimated Initial Cost	Estimated Annual O+M Cost	Present Value of Mitigation Costs (PV_c)		Estimated Reduction in Leachate Volume	Present Value of Avoided Costs (PV_a)		Net Present Costs PV_c + (NA–PV_a)	
			30 yrs	50 yrs		30 yrs	50 yrs	30 yrs	50 yrs
Deep Trench	$30,406,000	$18,400	$34,228,000	$34,233,000	90% (59 gpm)	$1,660,000	$1,745,000	$35,120,000	$35,135,000
Extraction Wells/ Rock Fracturing	$8,042,000	$47,000	$9,414,000	$9,429,000	90% (59 gpm)	$1,660,000	$1,745,000	$10,306,000	$10,331,000
Medium Depth South Trench	$2,574,000	$3,700	$2,917,000	$2,918,000	10% (6.5 gpm)	$255,000	$265,000	$5,214,000	$5,300,000
Line Garden Creek	$1,090,000	$3,000	$1,247,900	$1,248,000	1.25% (0.8 gpm)	$31,900	$33,100	$3,768,000	$3,861,900
Line South Pond	$863,000	$1,000	$975,500	$976,200	2.5% (1.6 gpm)	$63,800	$66,200	$3,463,700	$3,557,000
Line East Ditch	$368,000	$1,000	$422,300	$422,700	1.5% (1.0 gpm)	$38,300	$39,700	$2,936,000	$3,030,000
No Action with Doubled Disposal Capacity [a]	$1,400,000	$133,000	$840,000	$880,000	0	$0	$0	$3,390,000	$3,527,000
No Action with Disposal Capacity Increased by 20,000 gpd	$132,100	$700	$138,100	$138,300	0	$191,400	$198,500	$2,499,000	$2,587,000
No Action (NA) [b]	--	$300,000	$2,552,000	$2,647,000	0	$0	$0	$2,552,000	$2,647,000

Notes:

Actual costs could be up to 35 percent higher or 50 percent lower than the values shown for each alternative.
a) Costs assume capacity will require doubling in the year 2005 due to Regional Landfill discharges.
b) No Action Alternative costs based on 1995 Silver Lake water district fees.

AGI
TECHNOLOGIES

Table 10
Estimated Present Value of Costs over 30 years to Dispose Flows > 144,000 gpd Under the No Action Alternative

Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

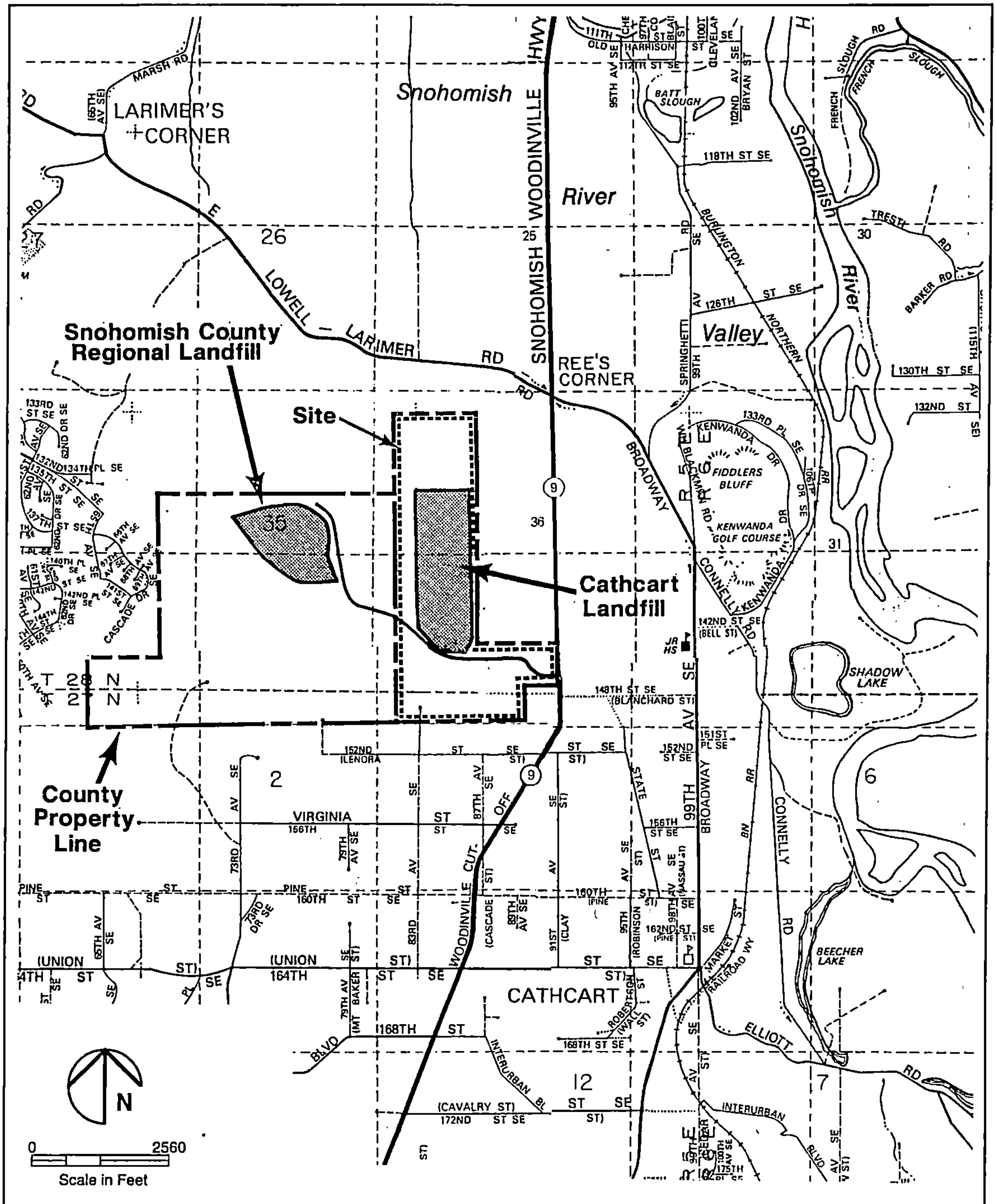
	No. of 221 gpd increments	Thousands of gallons per day	①					②				Volume of Leachate Trucked by Tanker X 1,000 (gal/yr)											
			200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	30	20	10	0
Additional Capacity Purchased from SLWD	0	0	$191,389	$181,820	$172,250	$162,681	$153,111	$143,542	$133,972	$124,403	$114,833	$105,264	$95,695	$86,125	$76,556	$66,986	$57,417	$47,847	$38,278	$28,708	$19,139	$9,569	$0
	4.5	1	$198,294	$188,724	$179,155	$169,585	$160,016	$150,446	$140,877	$131,308	$121,738	$112,169	$102,599	$93,030	$83,460	$73,891	$64,321	$54,752	$45,182	$35,613	$26,044	$16,474	$6,905
	9.0	2	$205,198	$195,629	$186,059	$176,490	$166,921	$157,351	$147,782	$138,212	$128,643	$119,073	$109,504	$99,934	$90,365	$80,795	$71,226	$61,657	$52,087	$42,518	$32,948	$23,379	$13,809
	13.6	3	$212,103	$202,534	$192,964	$183,395	$173,825	$164,256	$164,686	$145,117	$135,547	$125,978	$116,408	$106,839	$97,270	$87,700	$78,131	$68,561	$58,992	$49,422	$39,853	$30,283	$20,714
	18.1	4	$219,008	$209,438	$199,869	$190,299	$180,730	$171,160	$161,591	$152,021	$142,452	$132,883	$123,313	$113,744	$104,174	$94,605	$85,035	$75,466	$65,896	$56,327	$46,757	$37,188	$27,619
	22.6	5	$225,912	$216,343	$206,773	$197,204	$187,634	$178,065	$168,496	$158,926	$149,357	$139,787	$130,218	$120,648	$111,079	$101,509	$91,940	$82,370	$72,801	$63,232	$53,662	$44,093	$34,523
	27.1	6	$232,817	$223,247	$213,678	$204,109	$194,539	$184,970	$175,400	$165,831	$156,261	$146,692	$137,122	$127,553	$117,983	$108,414	$98,845	$89,275	$79,706	$70,136	$60,567	$50,997	$41,428
	31.7	7	$239,722	$230,152	$220,583	$211,013	$201,444	$191,874	$182,305	$172,735	$163,166	$153,596	$144,027	$134,458	$124,888	$115,319	$105,749	$96,180	$86,610	$77,041	$67,471	$57,902	$48,333
	36.2	8	$246,626	$237,057	$227,487	$217,918	$208,348	$198,779	$189,210	$179,640	$170,071	$160,501	$150,932	$141,362	$131,793	$122,223	$112,654	$103,084	$93,515	$83,946	$74,376	$64,807	$55,237
	40.7	9	$253,531	$243,961	$234,392	$224,823	$215,253	$205,684	$196,114	$186,545	$176,975	$167,406	$157,836	$148,267	$138,697	$129,128	$119,559	$109,989	$100,420	$90,850	$81,281	$71,711	$62,142
	45.2	10	$260,436	$250,866	$241,297	$231,727	$222,158	$212,588	$203,019	$193,449	$183,880	$174,310	$164,741	$155,172	$145,602	$136,033	$126,463	$116,894	$107,324	$97,755	$88,185	$78,616	$69,046
	49.6	11	$267,340	$257,771	$248,201	$238,632	$229,062	$219,493	$209,923	$200,354	$190,785	$181,215	$171,646	$162,076	$152,507	$142,937	$133,368	$123,798	$114,229	$104,659	$95,090	$85,521	$75,951
	54.3	12	$274,245	$264,675	$255,106	$245,536	$235,967	$226,398	$216,828	$207,259	$197,689	$188,120	$178,550	$168,981	$159,411	$149,842	$140,272	$130,703	$121,134	$111,564	$101,995	$92,425	$82,856
	58.8	13	$281,149	$271,580	$262,011	$252,441	$242,872	$233,302	$223,733	$214,163	$204,594	$195,024	$185,455	$175,885	$166,316	$156,747	$147,177	$137,608	$128,038	$118,469	$108,899	$99,330	$89,760
	63.3	14	$288,054	$278,485	$268,915	$259,346	$249,776	$240,207	$230,637	$221,068	$211,498	$201,929	$192,360	$182,790	$173,221	$163,651	$154,082	$144,512	$134,943	$125,373	$115,804	$106,235	$96,665
	67.9	15	$294,959	$285,389	$275,820	$266,250	$256,681	$247,111	$237,542	$227,973	$218,403	$208,834	$199,264	$189,695	$180,125	$170,556	$160,986	$151,417	$141,848	$132,278	$122,709	$113,139	$103,570
	72.4	16	$301,863	$292,294	$282,724	$273,155	$263,586	$254,016	$244,447	$234,877	$225,308	$215,738	$206,169	$196,599	$187,030	$177,461	$167,891	$158,322	$148,752	$139,183	$129,613	$120,044	$110,474
	76.9	17	$308,768	$299,199	$289,629	$280,060	$270,490	$260,921	$251,351	$241,782	$232,212	$222,643	$213,074	$203,504	$193,935	$184,365	$174,796	$165,226	$155,657	$146,087	$136,518	$126,948	$117,379
	81.4	18	$315,673	$306,103	$296,534	$286,964	$277,395	$267,825	$258,256	$248,687	$239,117	$229,548	$219,978	$210,409	$200,839	$191,270	$181,700	$172,131	$162,561	$152,992	$143,423	$133,853	$124,284
	86.0	19	$322,577	$313,008	$303,438	$293,869	$284,300	$274,730	$265,161	$255,591	$246,022	$236,452	$226,883	$217,313	$207,744	$198,174	$188,605	$179,036	$169,466	$159,897	$150,327	$140,758	$131,188
	90.5	20	$329,482	$319,913	$310,343	$300,774	$291,204	$281,635	$272,065	$262,496	$252,926	$243,357	$233,787	$224,218	$214,649	$205,079	$195,510	$185,940	$176,371	$166,801	$157,232	$147,662	$138,093

Recommended
Action

Notes:

Recommeded Action is purchase of 20,000 gallons per day to eliminate all effluent off-hauling and trucking.
All costs are based on 1995 fees charged by Silver Lake Water District (SLWD).
Volume of leachate trucked costs include trucking ($0.052/gal) plus disposal costs ($0.0605/gal).
Additional capacity purchased costs include hookup fee (explained below) and disposal cost ($0.003507/gal) charged by SLWD.
Hookup fee is calculated using volume purchased (gpd) divided by 221 gpd, multiplied by $1,460. Additional capacity must be purchased in 221 gpd increments.
Effective interest rate used in present value calculation is 11.28% and includes inflation.

① Assumes overflow rate of 20,000 gpd occurs on 10 days out of the year.
② Assumes overflow rate of 15,000 gpd occurs on 10 days out of the year.



Reference: Map from Thomas Bros. Map Co., 1990 edition.

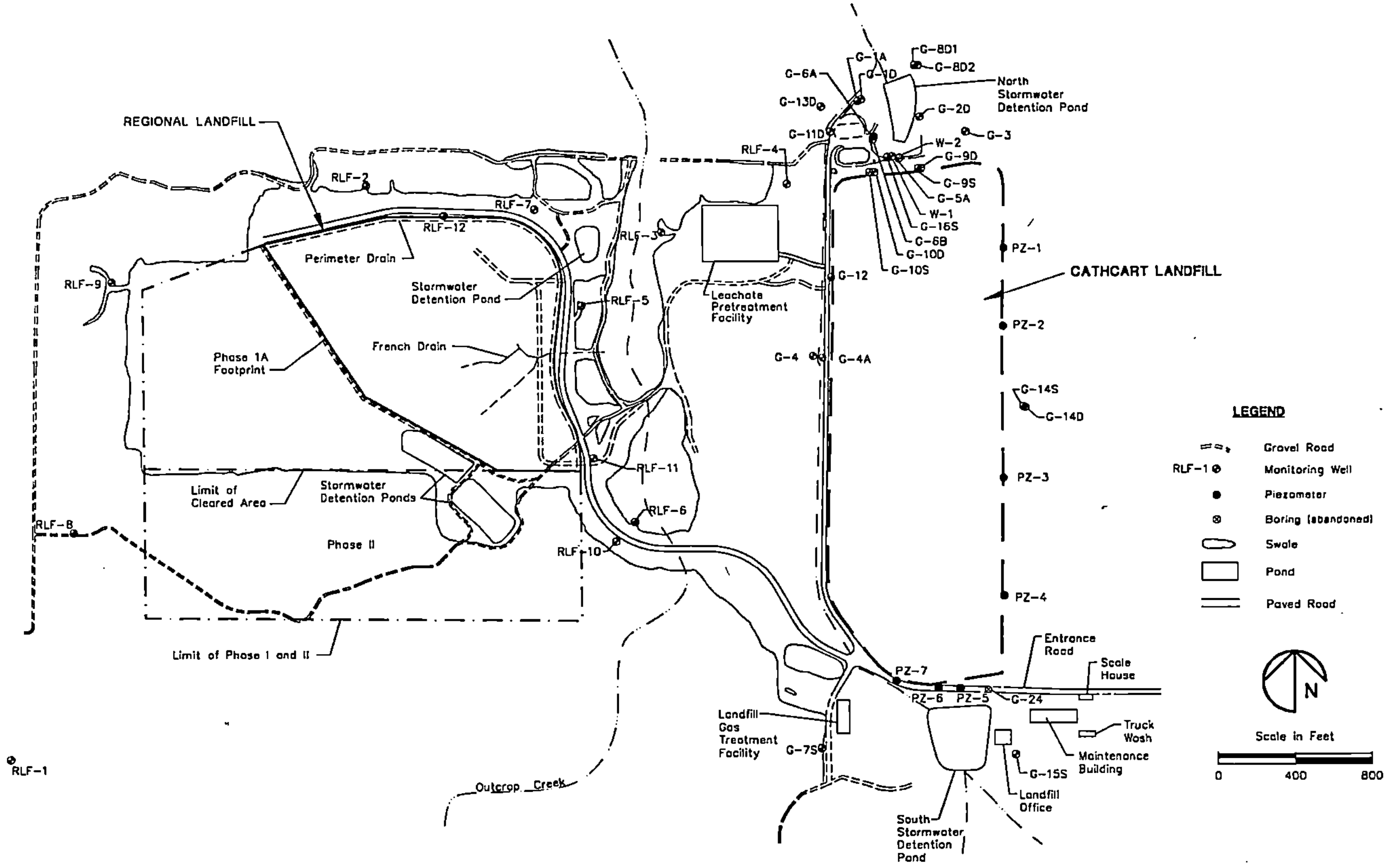
AGI TECHNOLOGIES

Vicinity Map

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE
1

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	JFL		TMH		



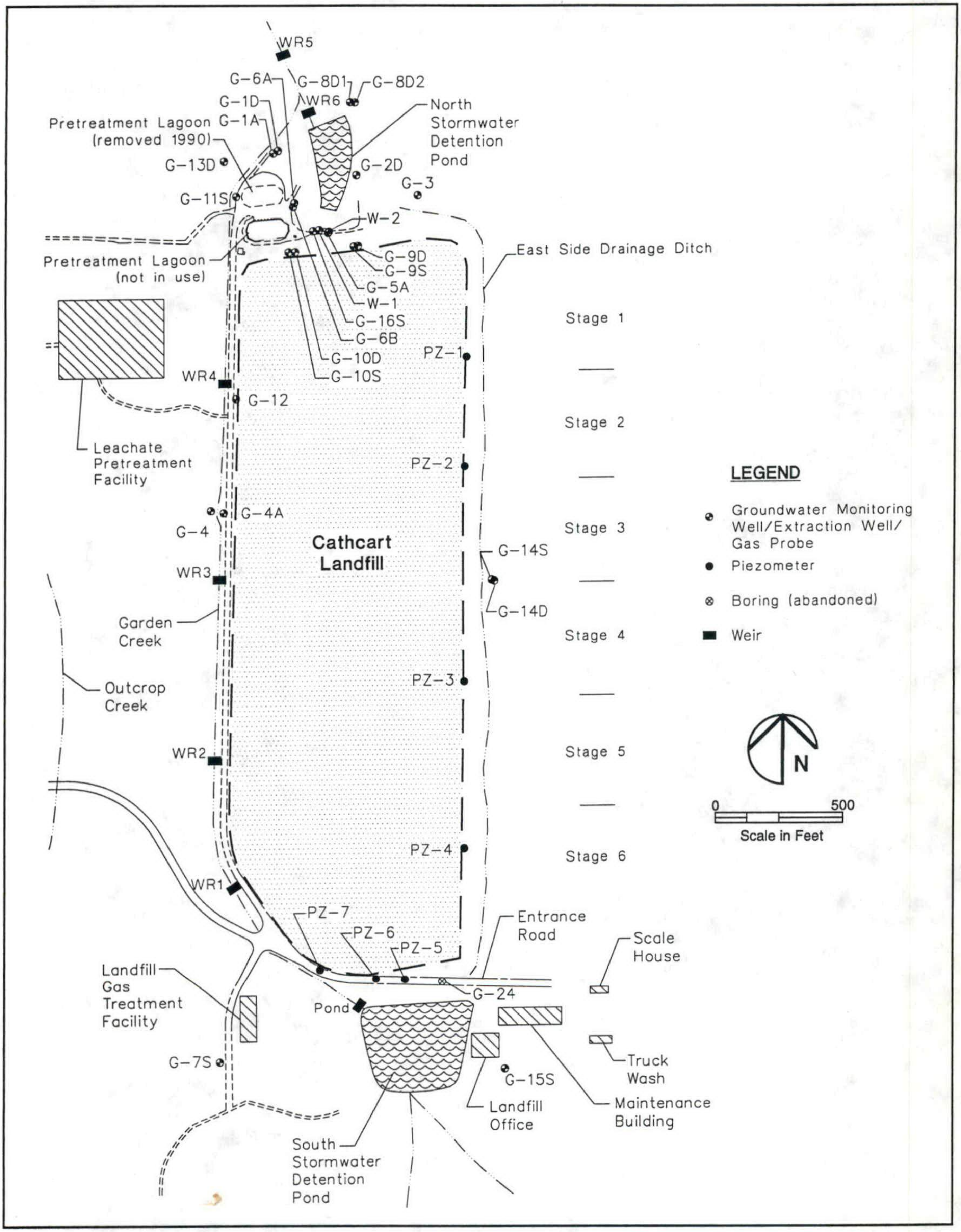
AGI
TECHNOLOGIES

Site Location Map

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE
2

	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
site.dwg	15,512.108	ALW	5 April 95	TMn		



AGI
TECHNOLOGIES

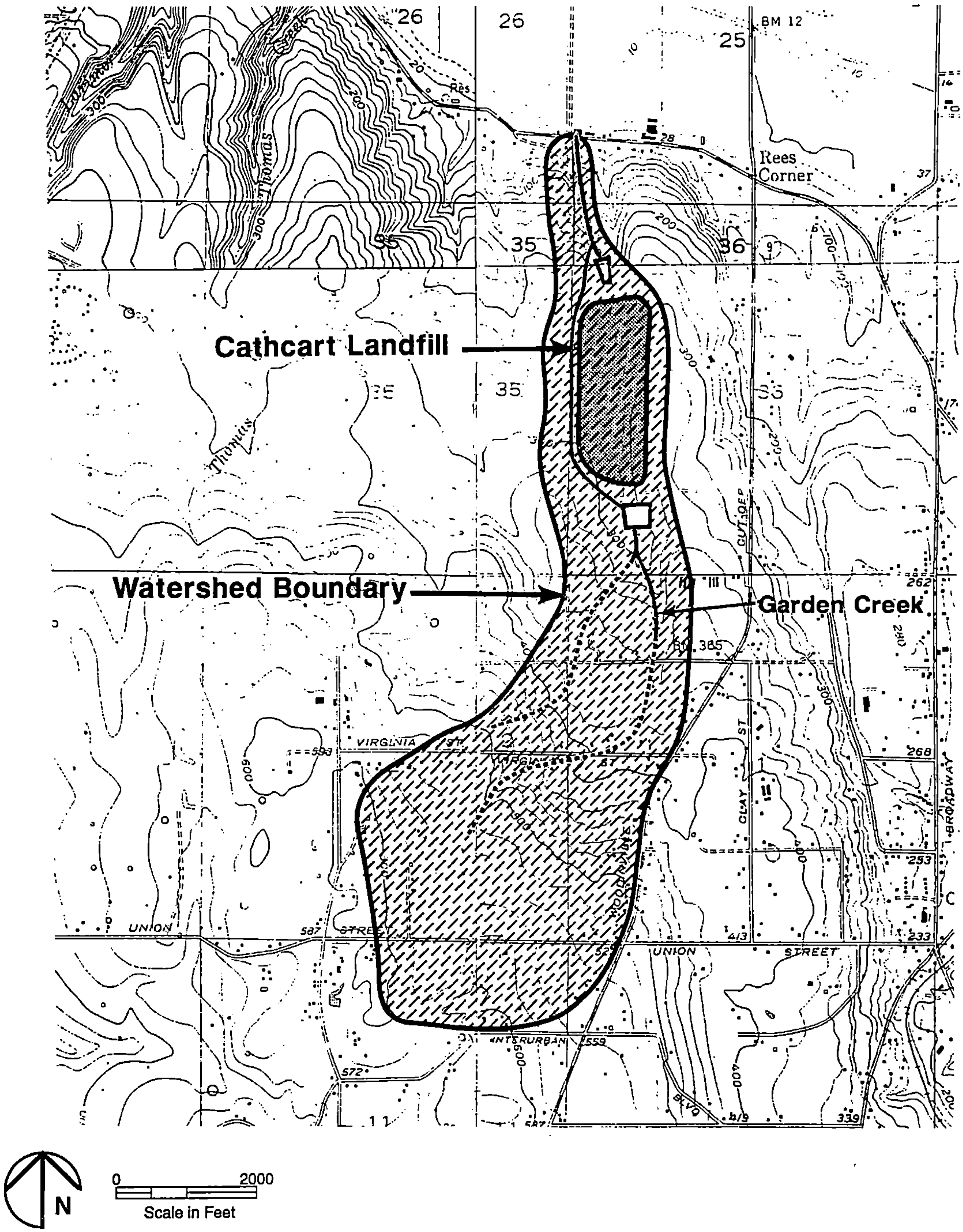
cathsite.dwg

Site Features

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE
3

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	ALW	6 April 95			



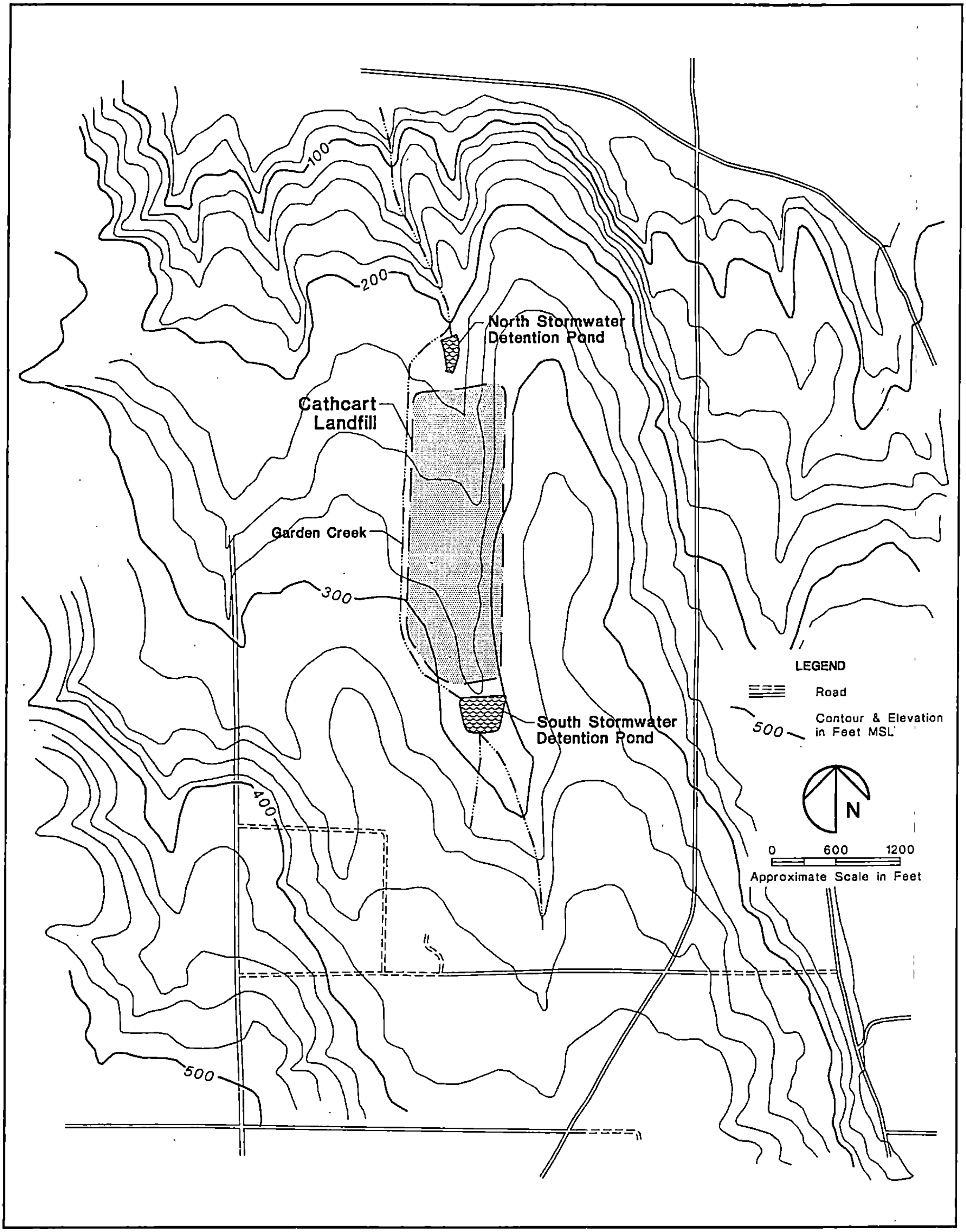
AGI
TECHNOLOGIES

Garden Creek Watershed

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE
4

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	ALW	6 April 95	TMW		



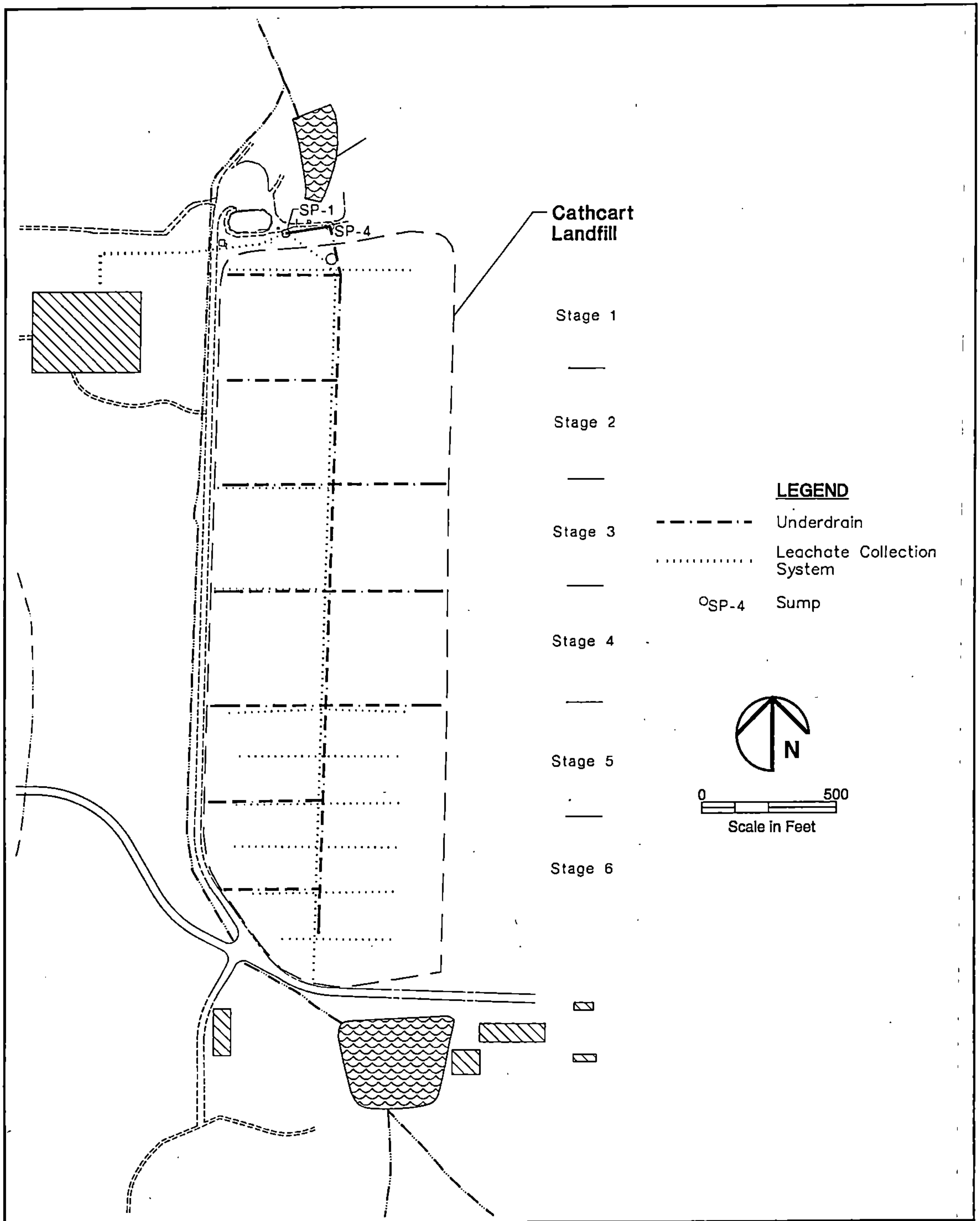
AGI
TECHNOLOGIES

Pre-Landfill Topography

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE
5

	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
cathtopo.dwg	15,512.108	ALW	6 April 95			



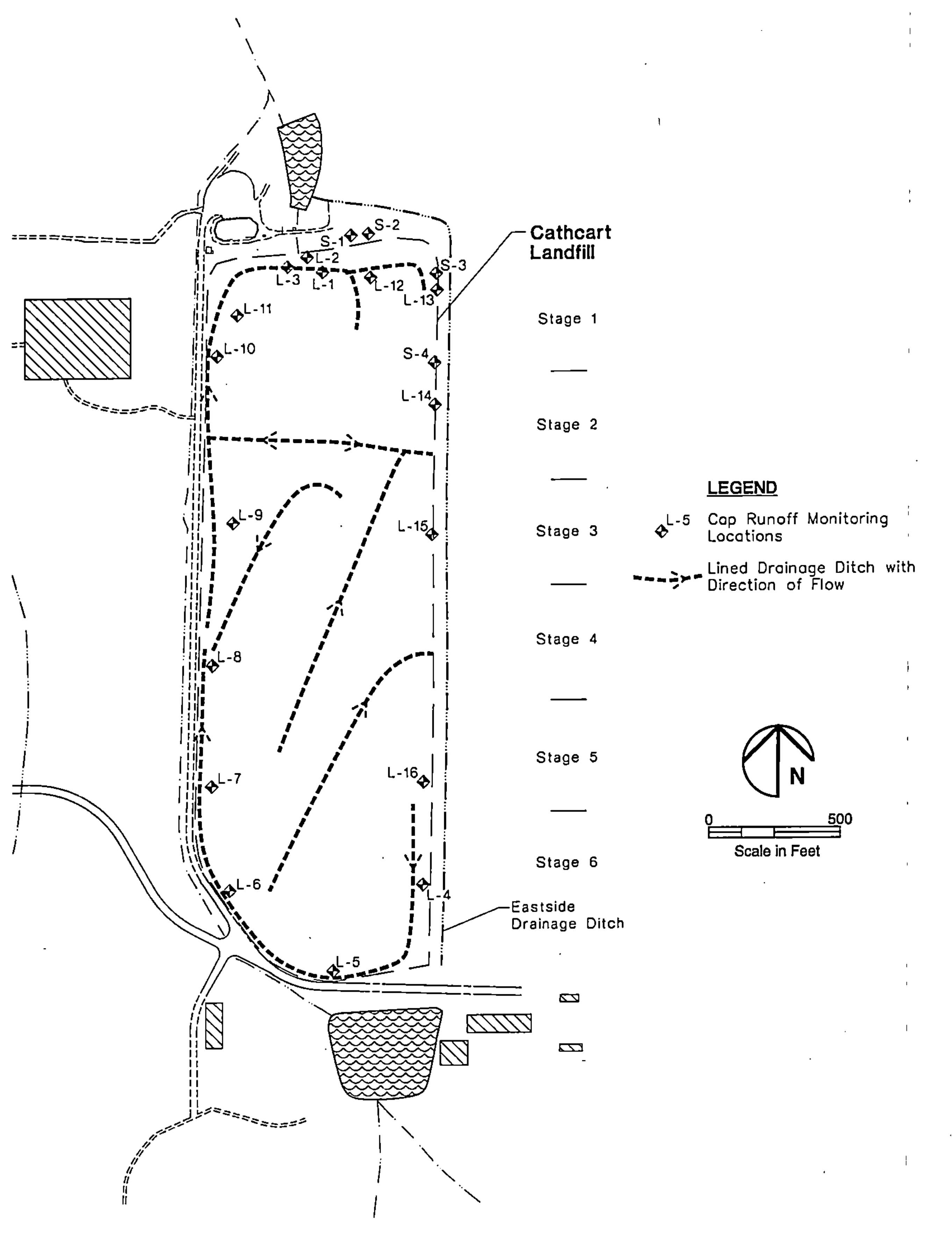
AGI TECHNOLOGIES

Underdrains & Leachate Collection Lines

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE
6

	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
cathutil.cdr	15,512.108	ALW/DFF	6 Apr 95			



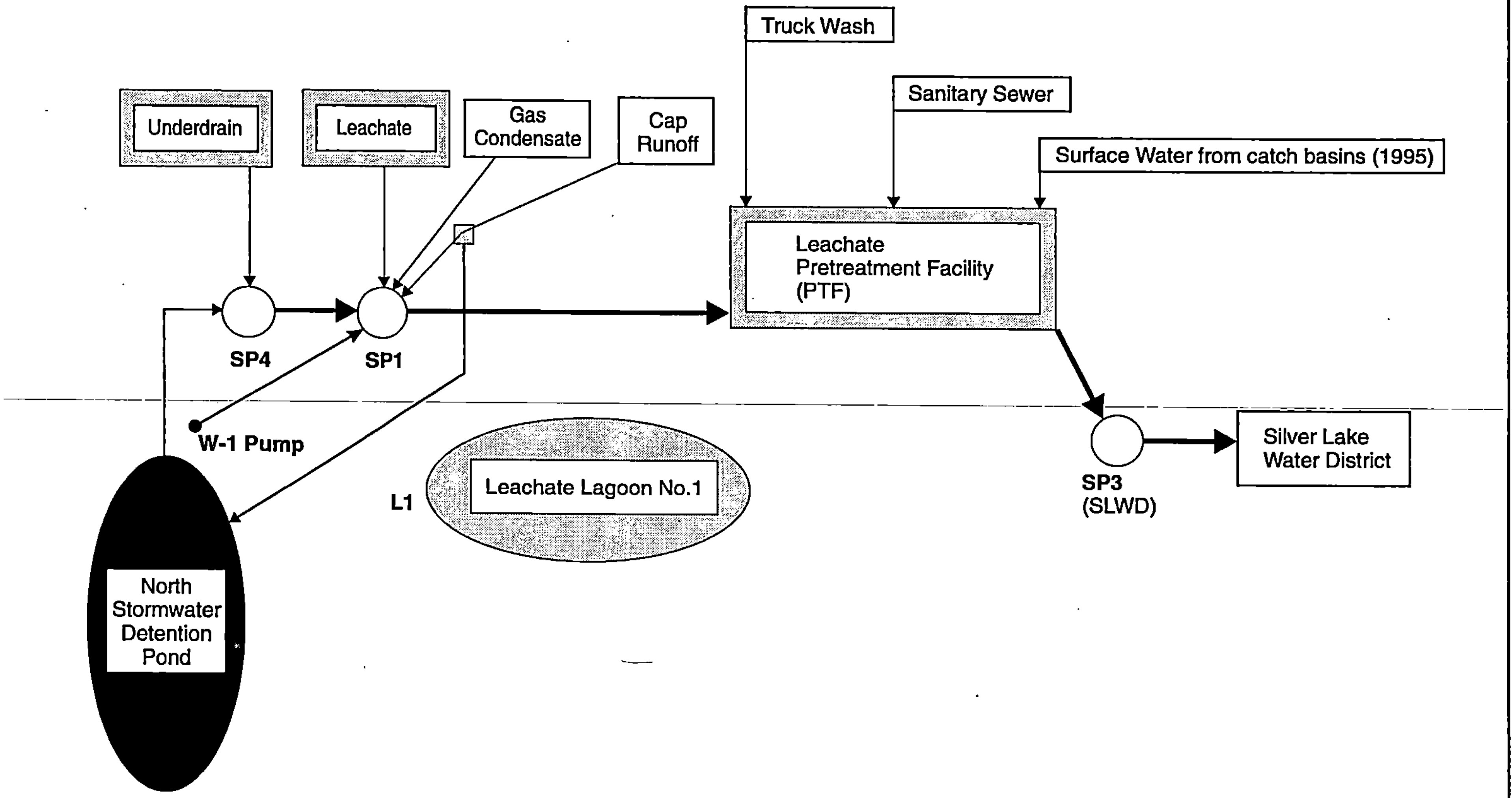
AGI
TECHNOLOGIES

Landfill Cap Runoff Monitoring Locations

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE
7

	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
runoff.dwg	15,512.108	ALW	6 April 95			



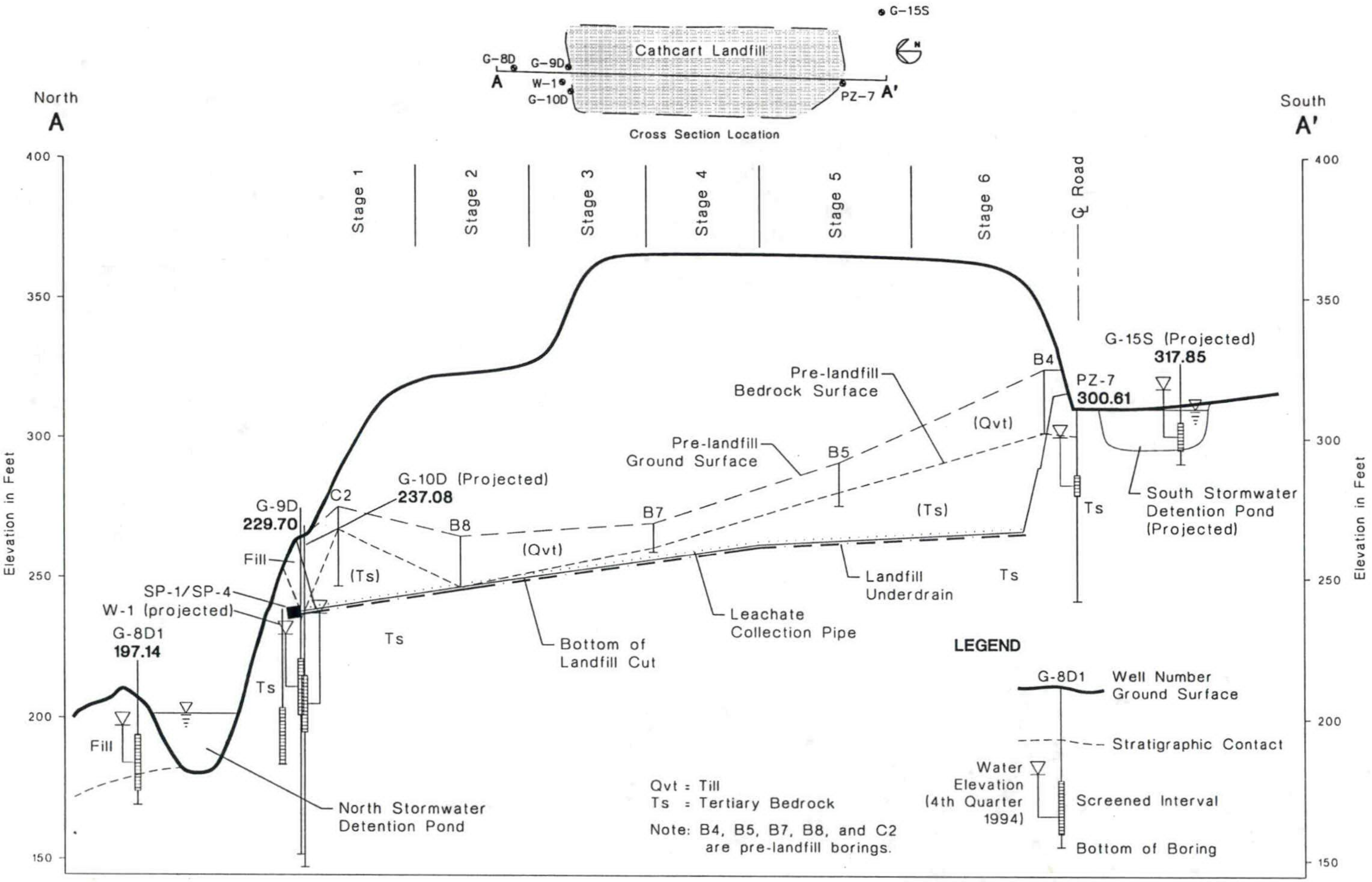
AGI
TECHNOLOGIES
conveydt.cdr

Cathcart Landfill North End Fluids Conveyance Detail

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE
8

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	6 Mar 95			



0 250 500

Horizontal Scale: 1"=500'
Vertical Scale: 1"=50'

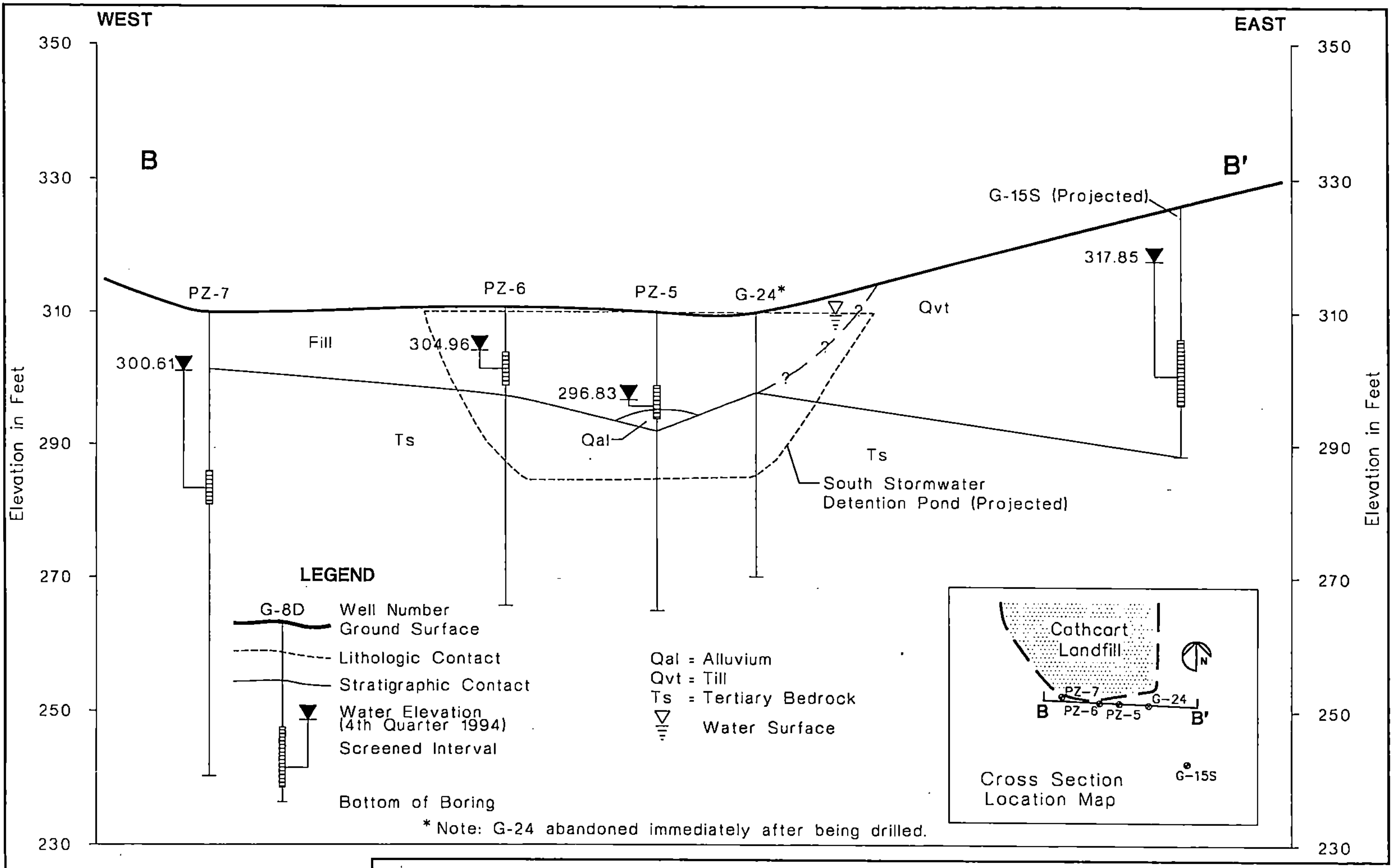
AGI
TECHNOLOGIES

Cross Section A - A'

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE
9

	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
secta-a.dwg	15,512.108	ALW	5 April 95			



* Note: G-24 abandoned immediately after being drilled.

0 100 200
Horizontal Scale: 1"=200'
Vertical Scale: 1"=20'

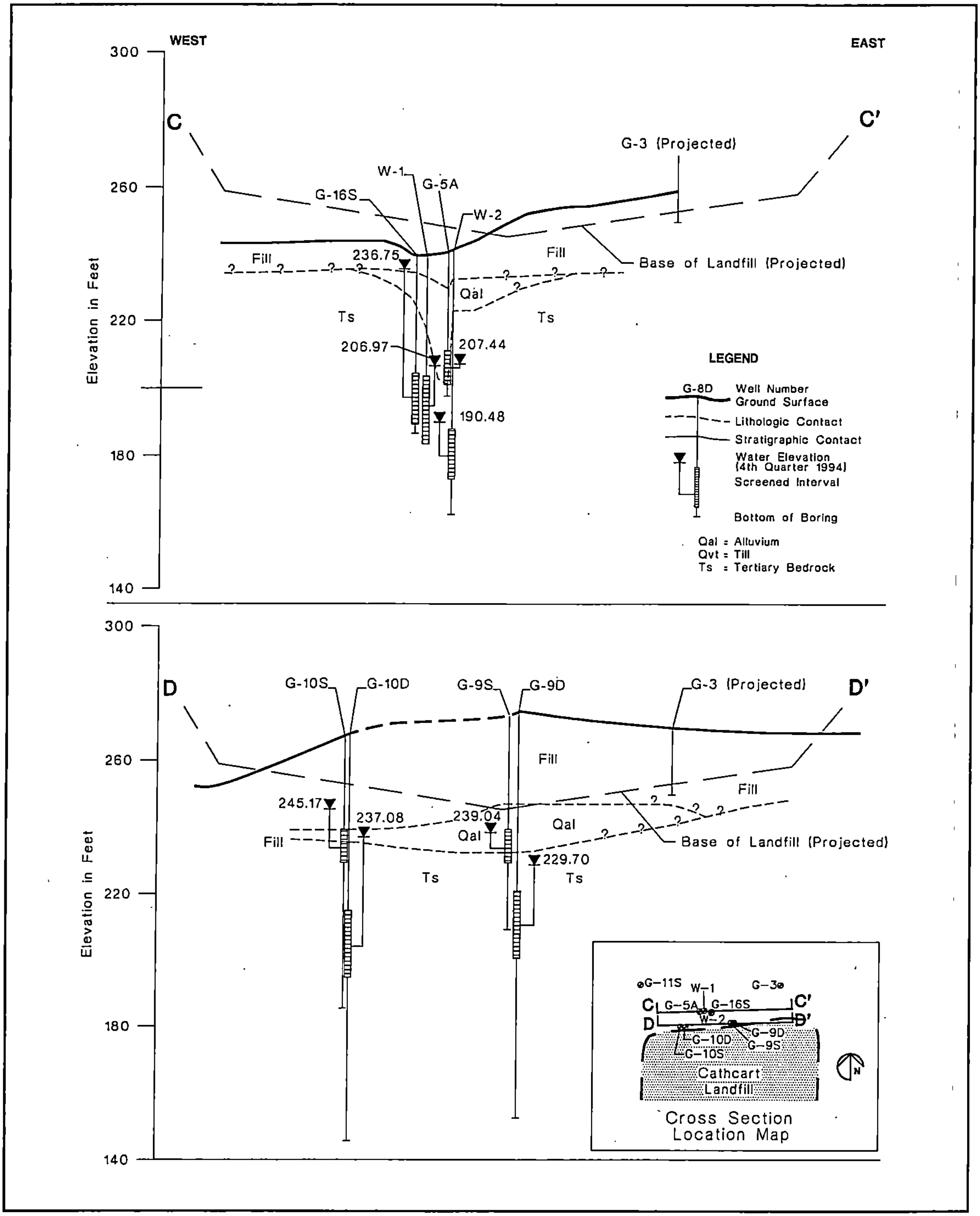
AGI
TECHNOLOGIES

Cross Section B - B'

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE
10

	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
sectb-b.dwg	15,512.108	ALW	5 April 95			



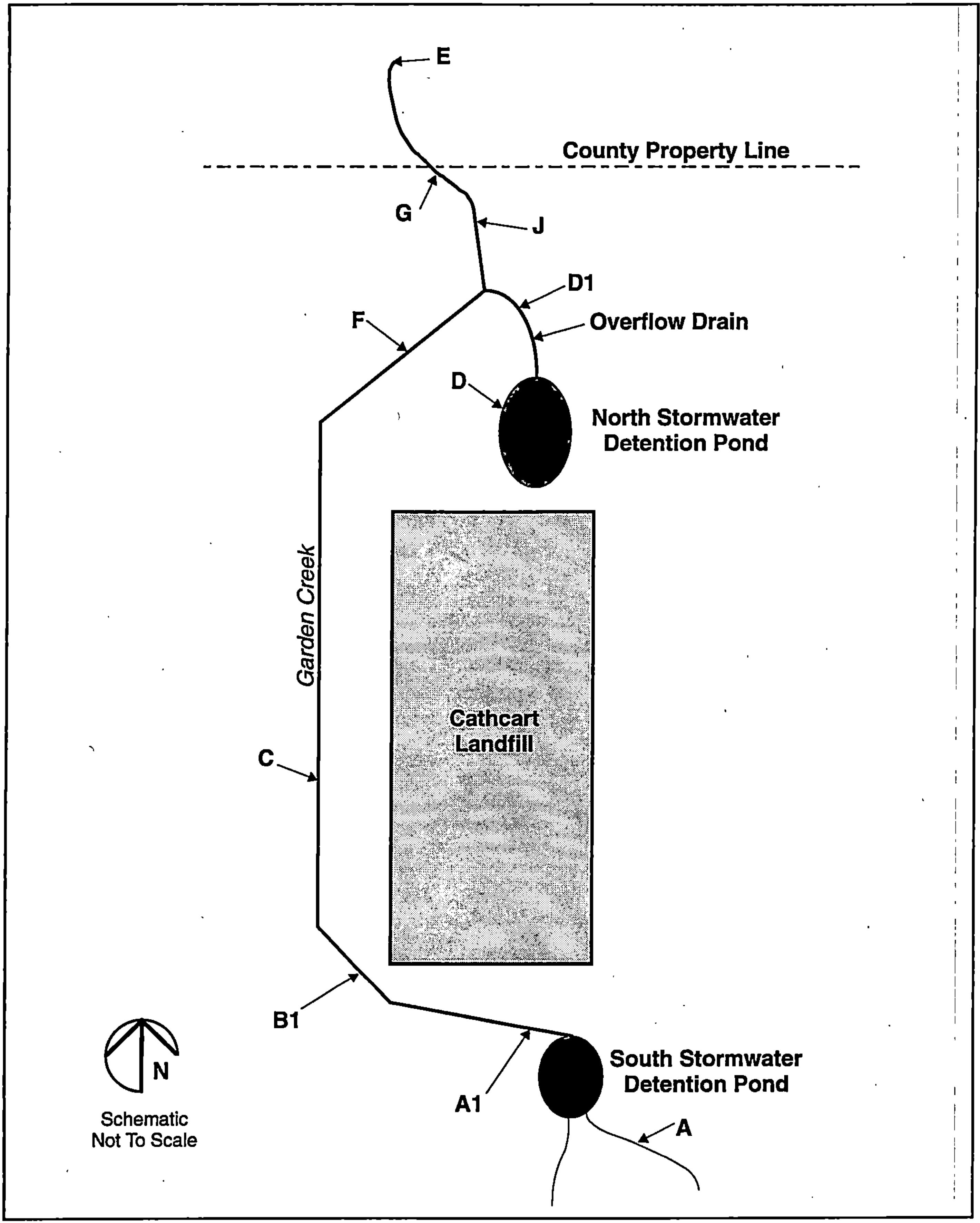
AGI
TECHNOLOGIES

Cross Sections C - C' & D - D'

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE
11

	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
sectc-d.dwg	15,512.108	ALW/DFF	6 Mar 95			



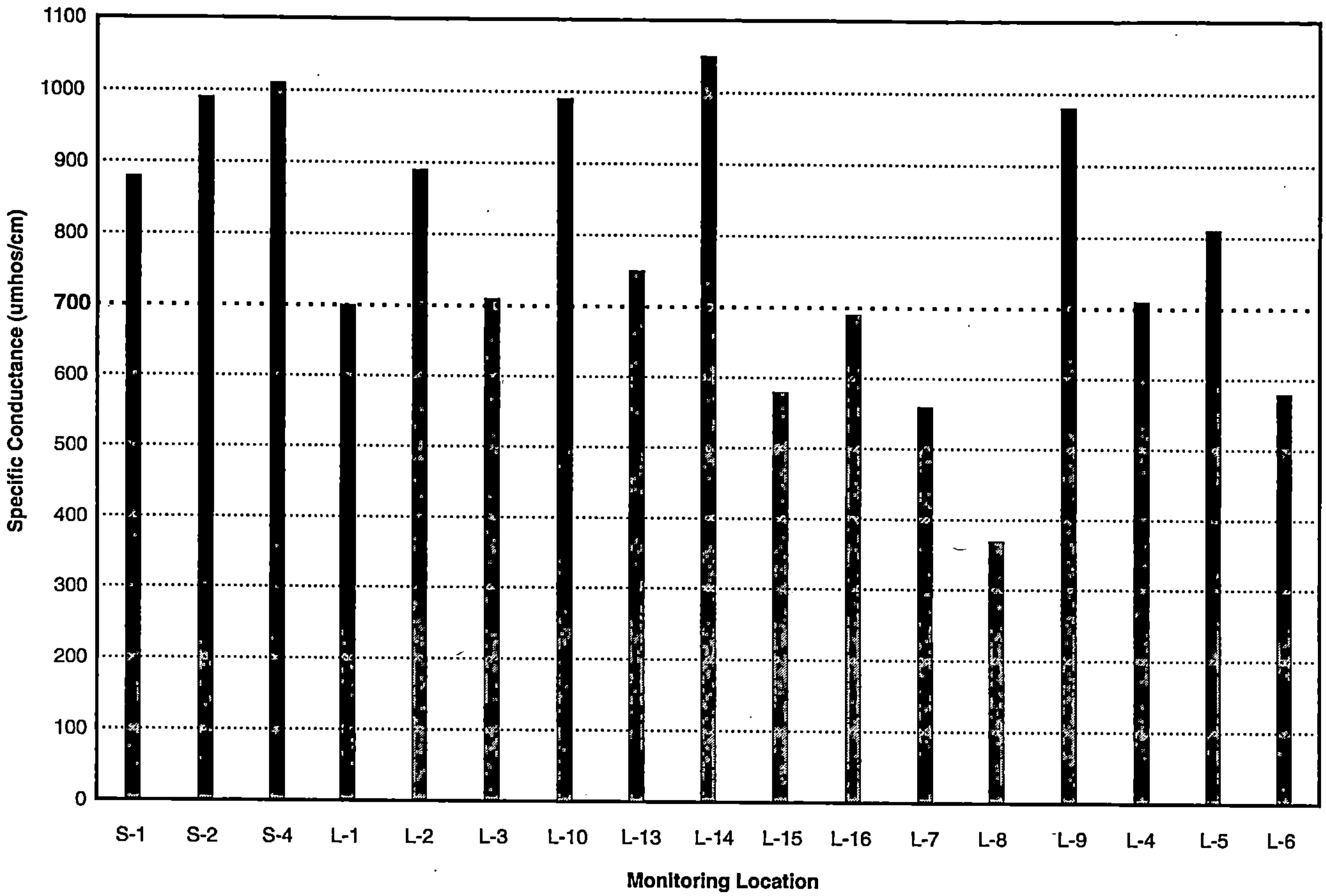
AGI TECHNOLOGIES

Surface Water Sampling Locations

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE 12

	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
smplocmp.cdr	15,512.108	DFF	6 Mar 95			



Note: Garden Creek discharge
action level = 700 umhos/cm

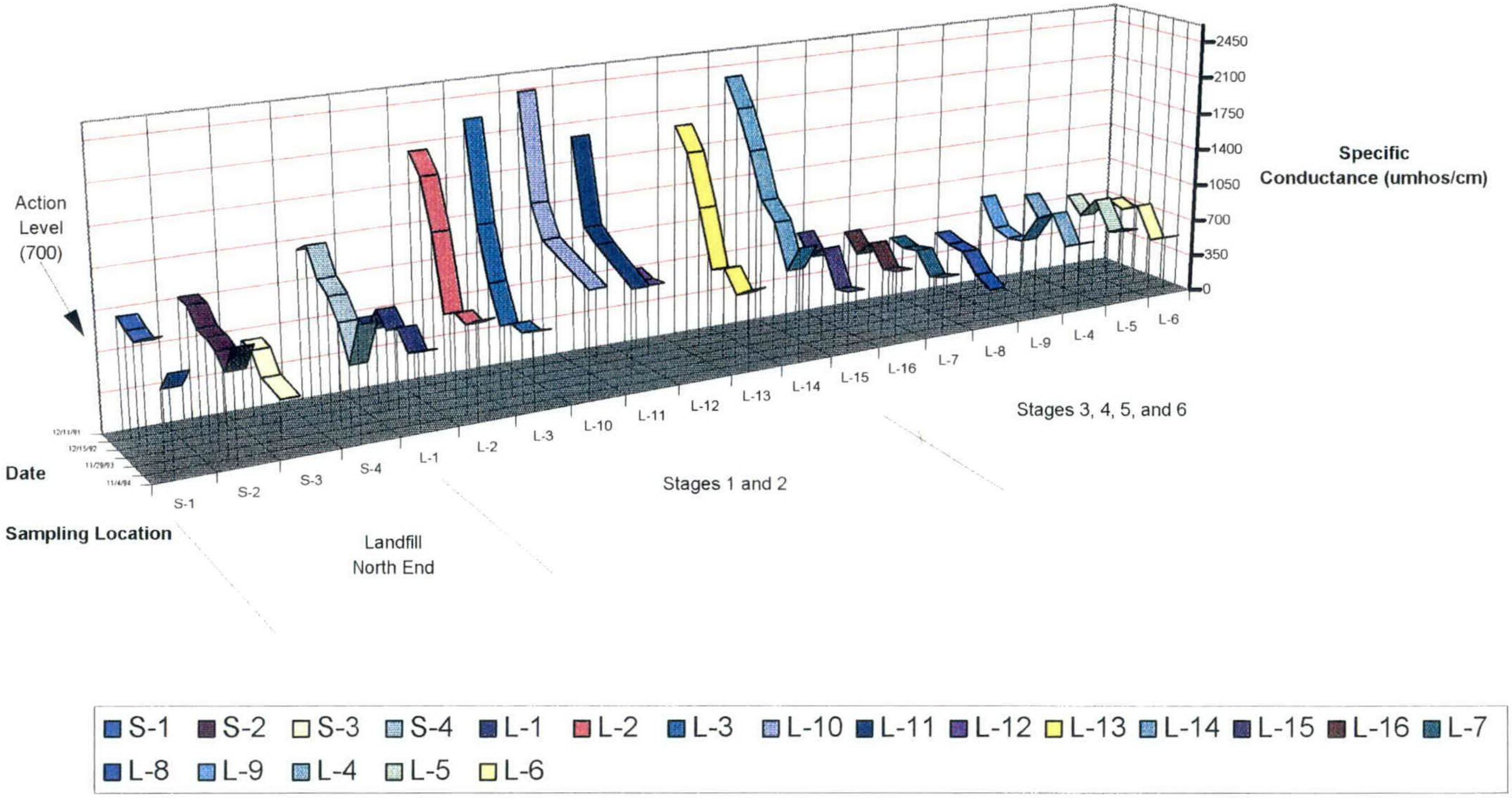
AGI TECHNOLOGIES

Landfill Cap Runoff Chemistry

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE **13**

	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
runchem.cdr	15,512.108	DFF	6 Mar 95			



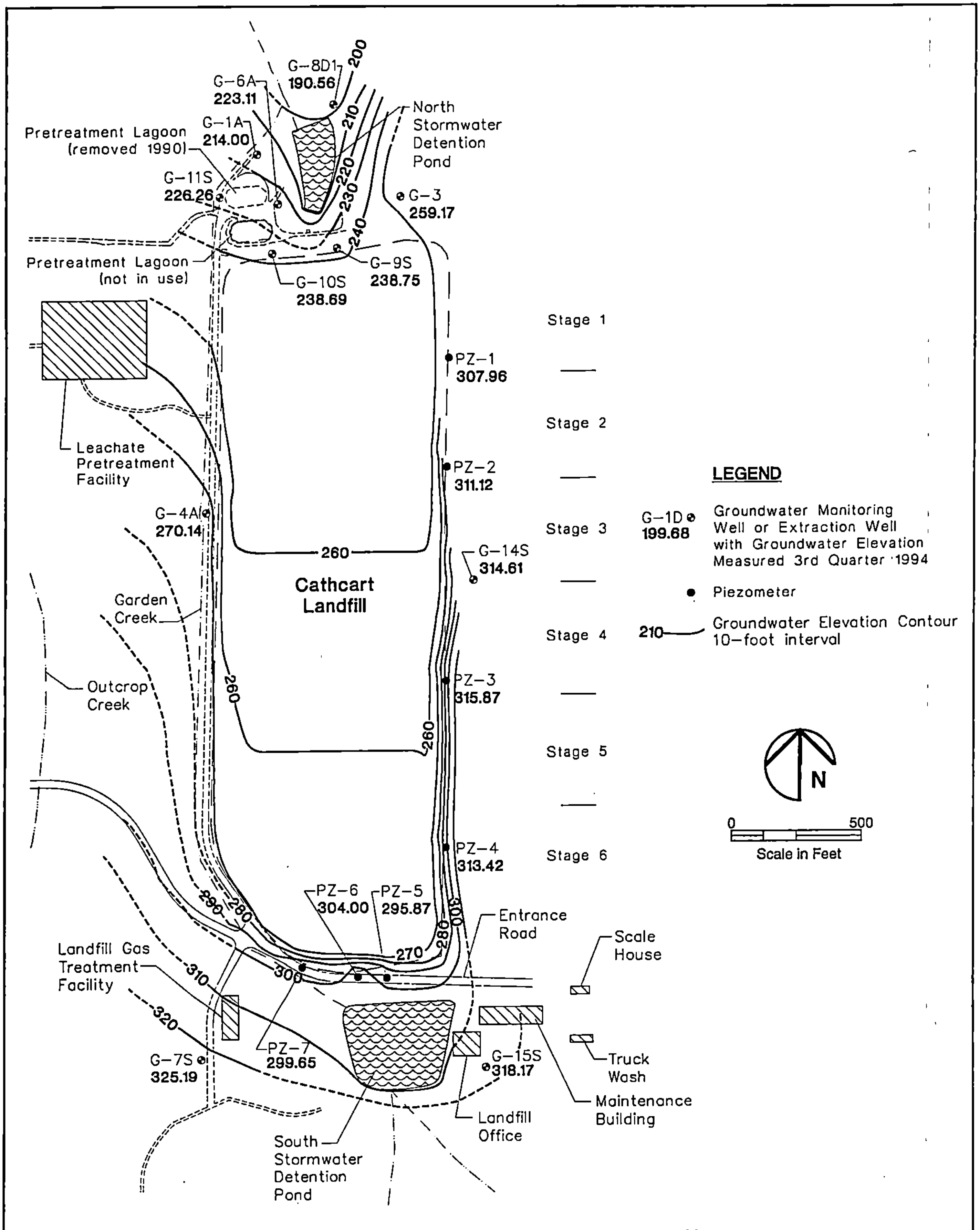
AGI TECHNOLOGIES

Cap Runoff - Specific Conductance

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE
14

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95	TMM		



3rd Quarter 1994 - Shallow Groundwater Zone

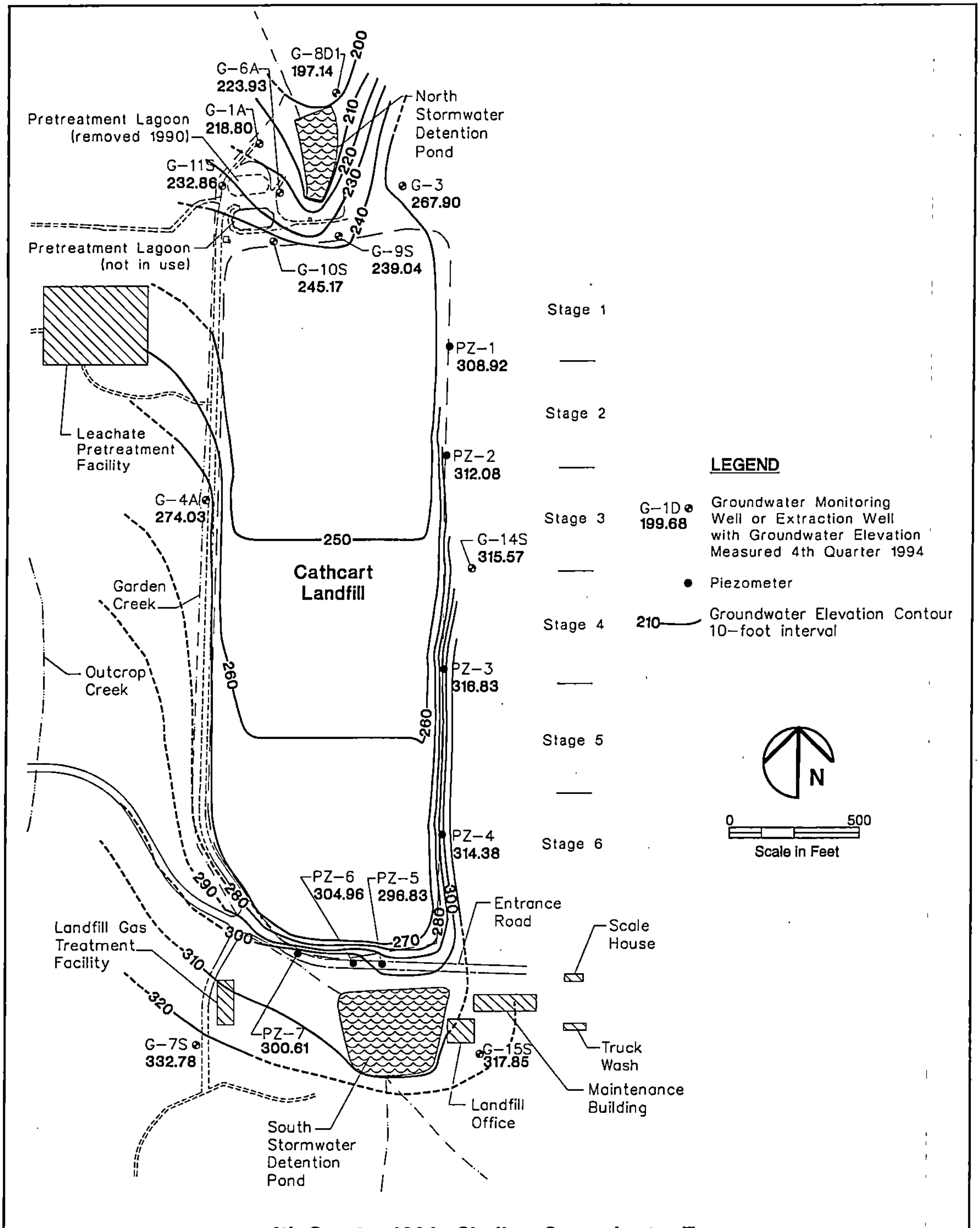
AGI
TECHNOLOGIES

Generalized Groundwater Contours & Flow Direction

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE
15

	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
394s.dwg	15,512.108	ALW	11 April 95			



4th Quarter 1994 - Shallow Groundwater Zone

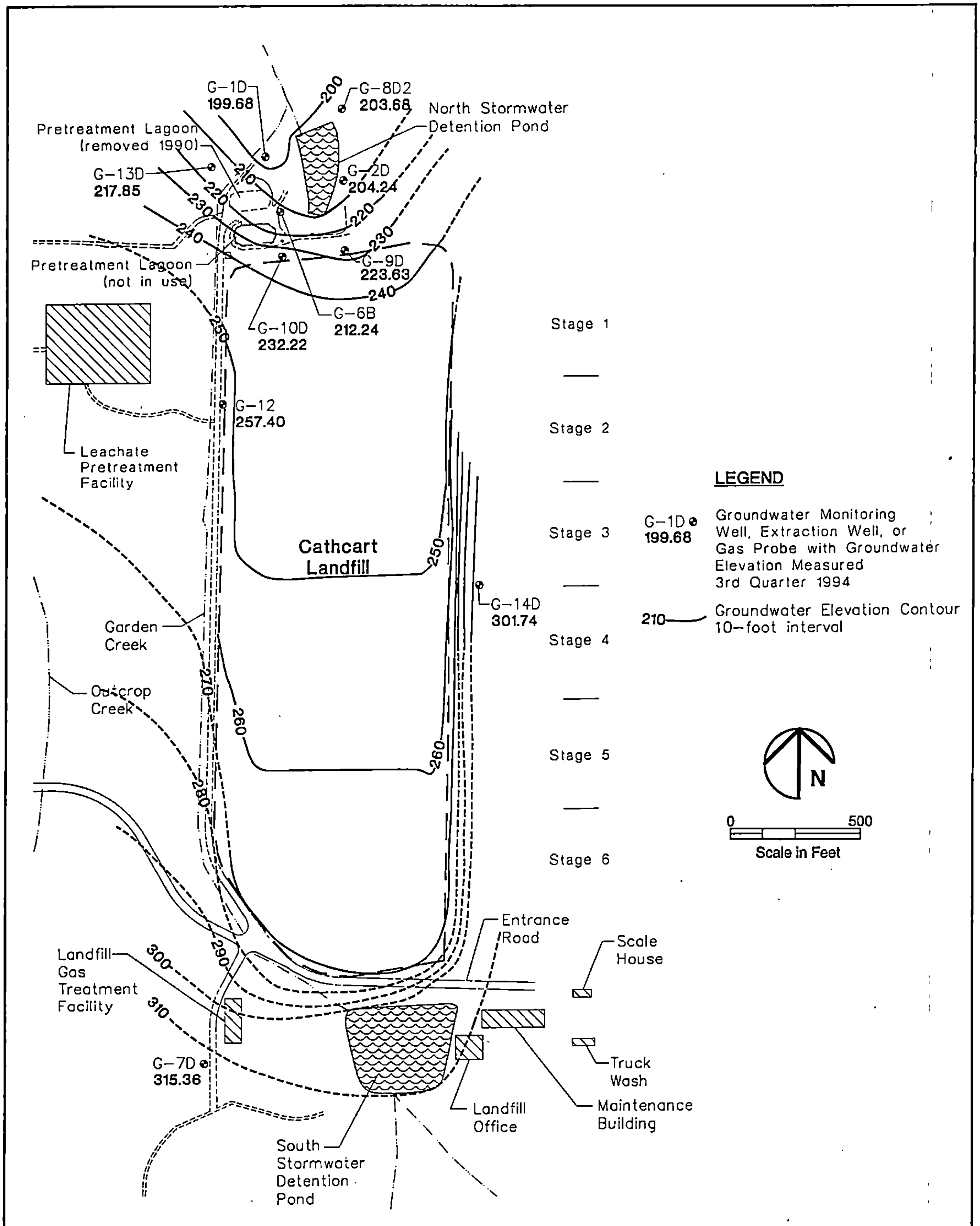
AGI
TECHNOLOGIES

Generalized Groundwater Contours & Flow Direction

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE
16

	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
494s.dwg	15,512.108	ALW	11 April 95			



3rd Quarter 1994 - Deep Groundwater Zone

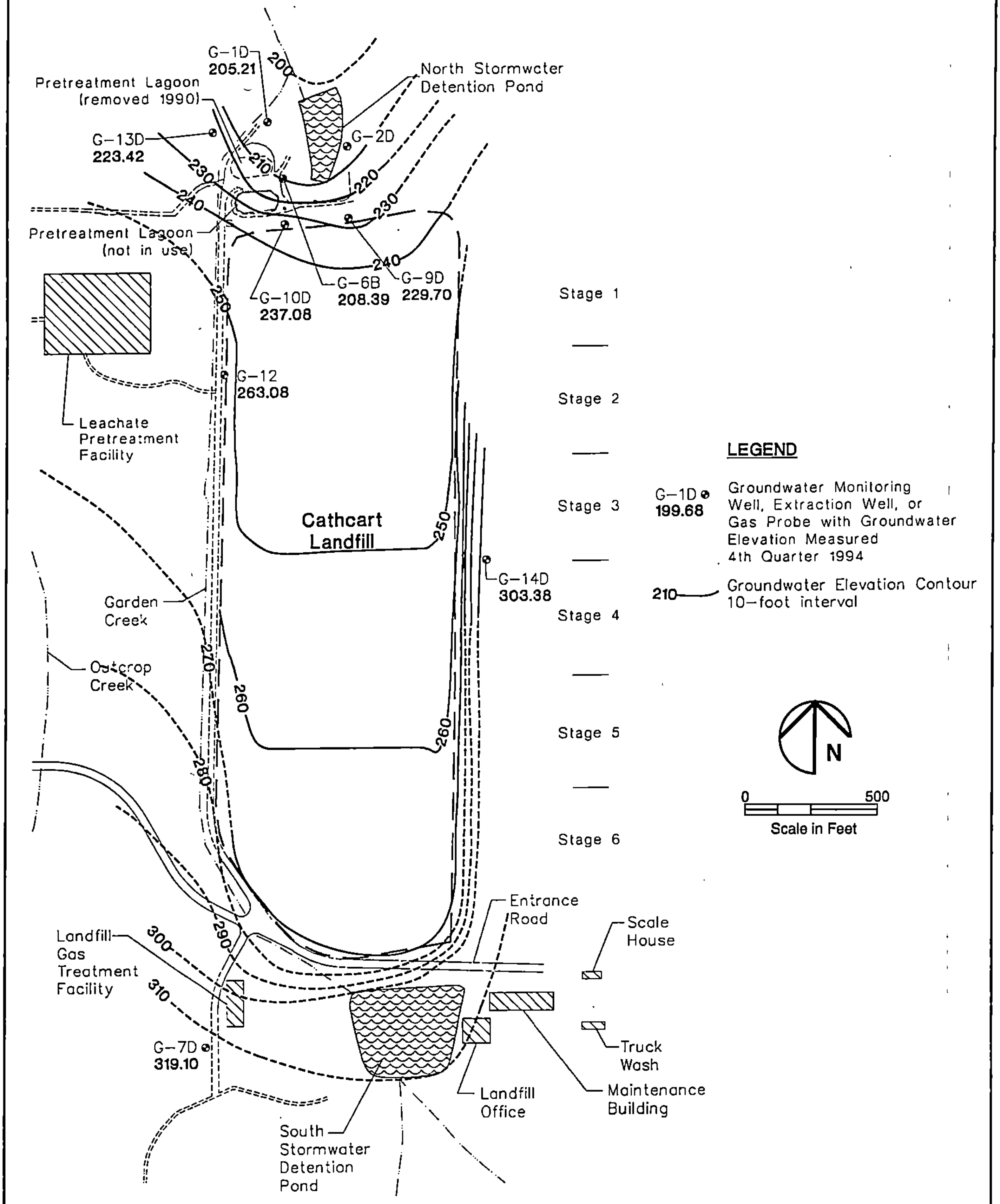
AGI
TECHNOLOGIES

Generalized Groundwater Contours & Flow Direction

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE
17

	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
394d.dwg	15,512.108	ALW	11 April 95			



4th Quarter 1994 - Deep Groundwater Zone

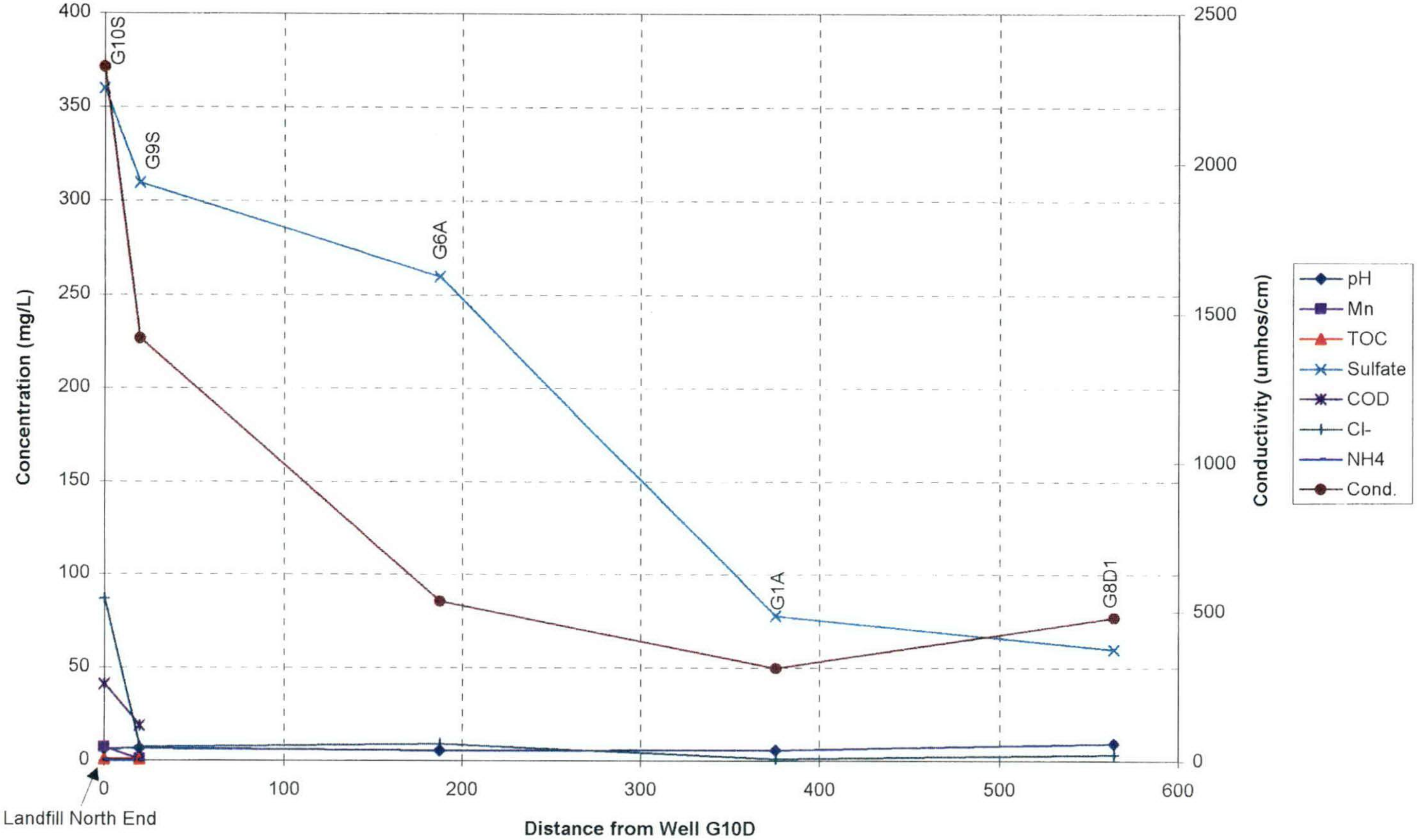
AGI
TECHNOLOGIES

Generalized Groundwater Contours & Flow Direction

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE
18

	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
494d.dwg	15,512.108	ALW	11 April 95			



Note: Data are from Fourth Quarter 1994.

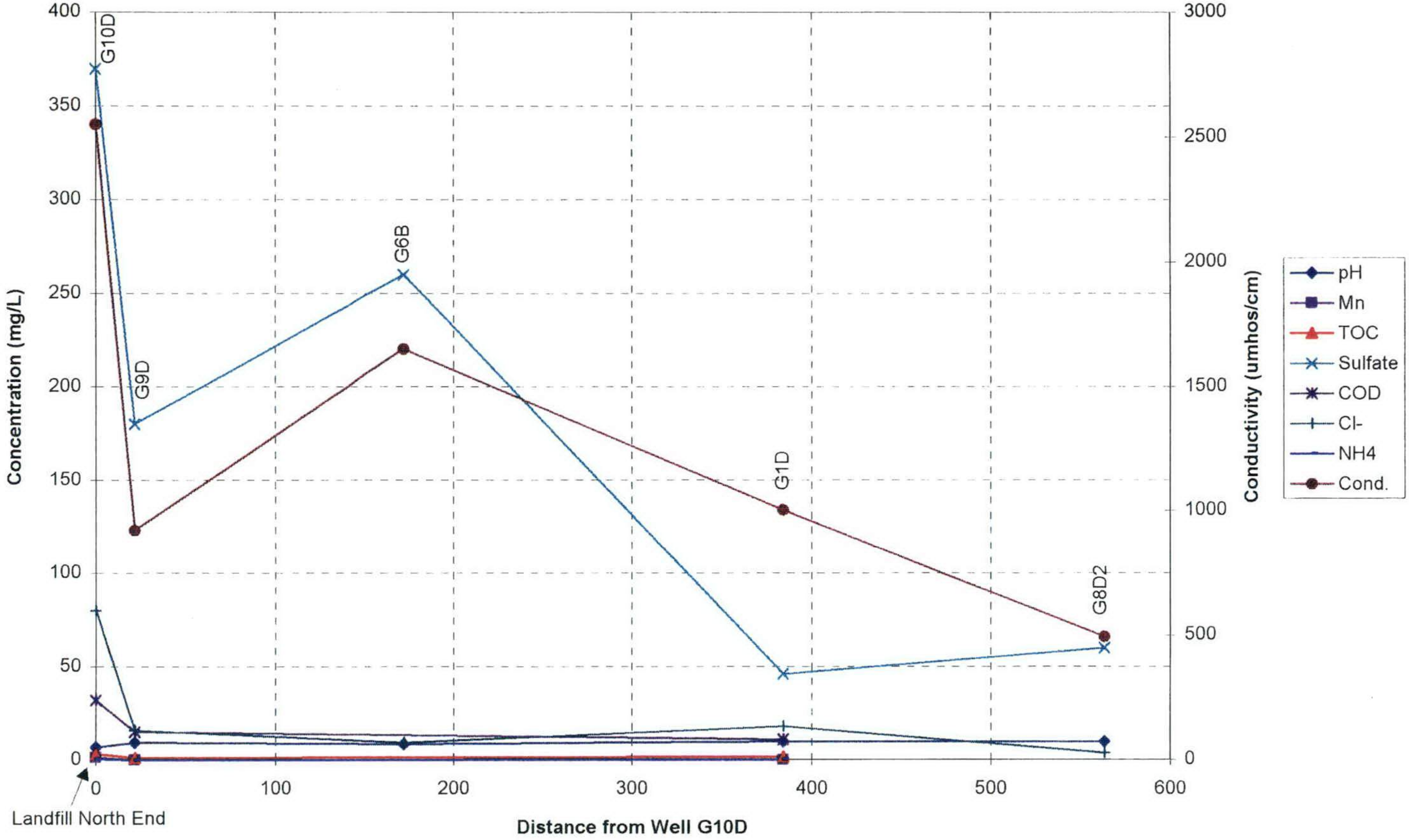
AGI
TECHNOLOGIES

Shallow Groundwater Chemistry Downgradient of Landfill

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE
19

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95	TMM		



Note: Data are from Fourth Quarter 1994.

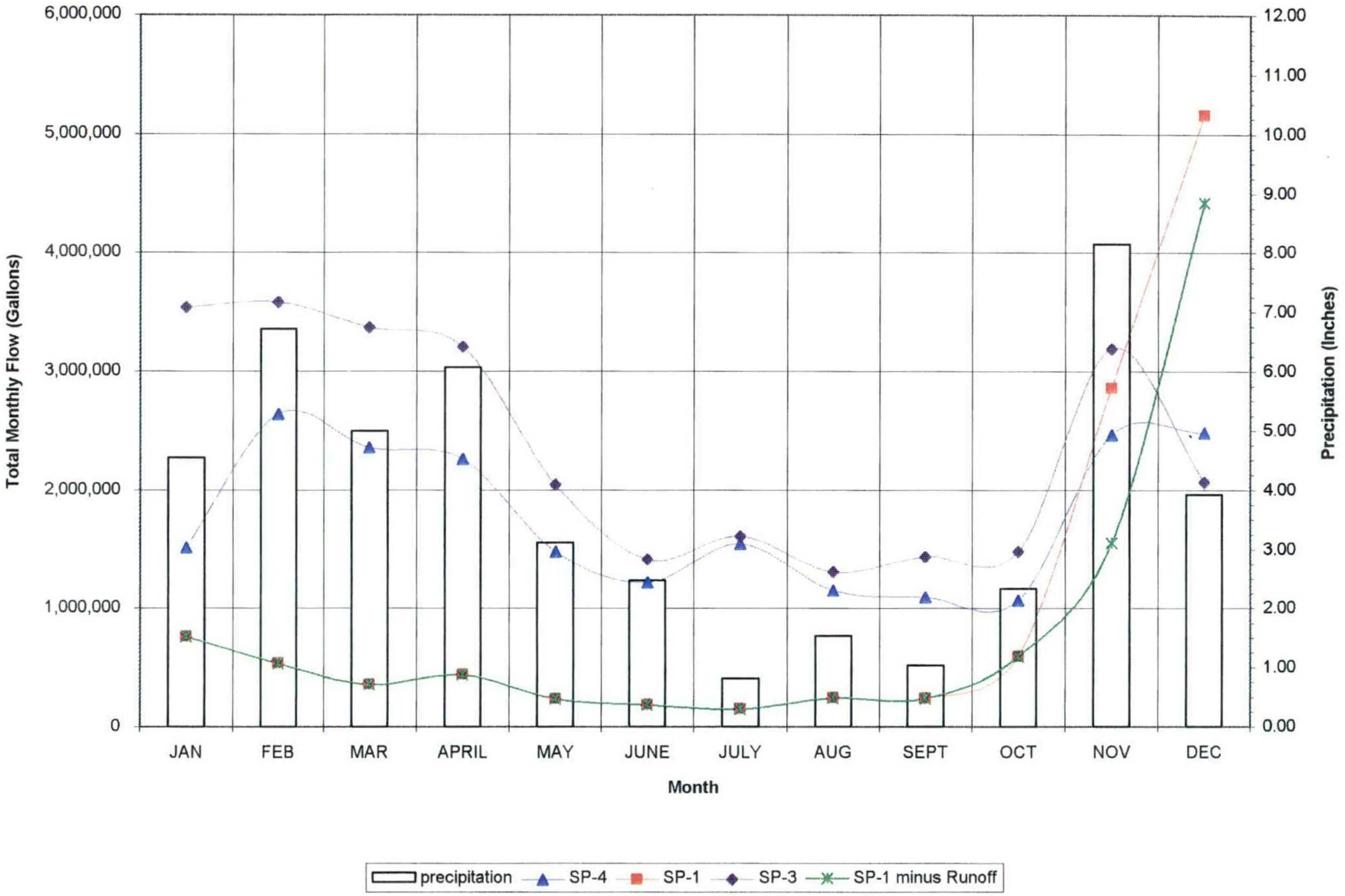
AGI TECHNOLOGIES

Deep Groundwater Chemistry Downgradient of Landfill

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE
20

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95			



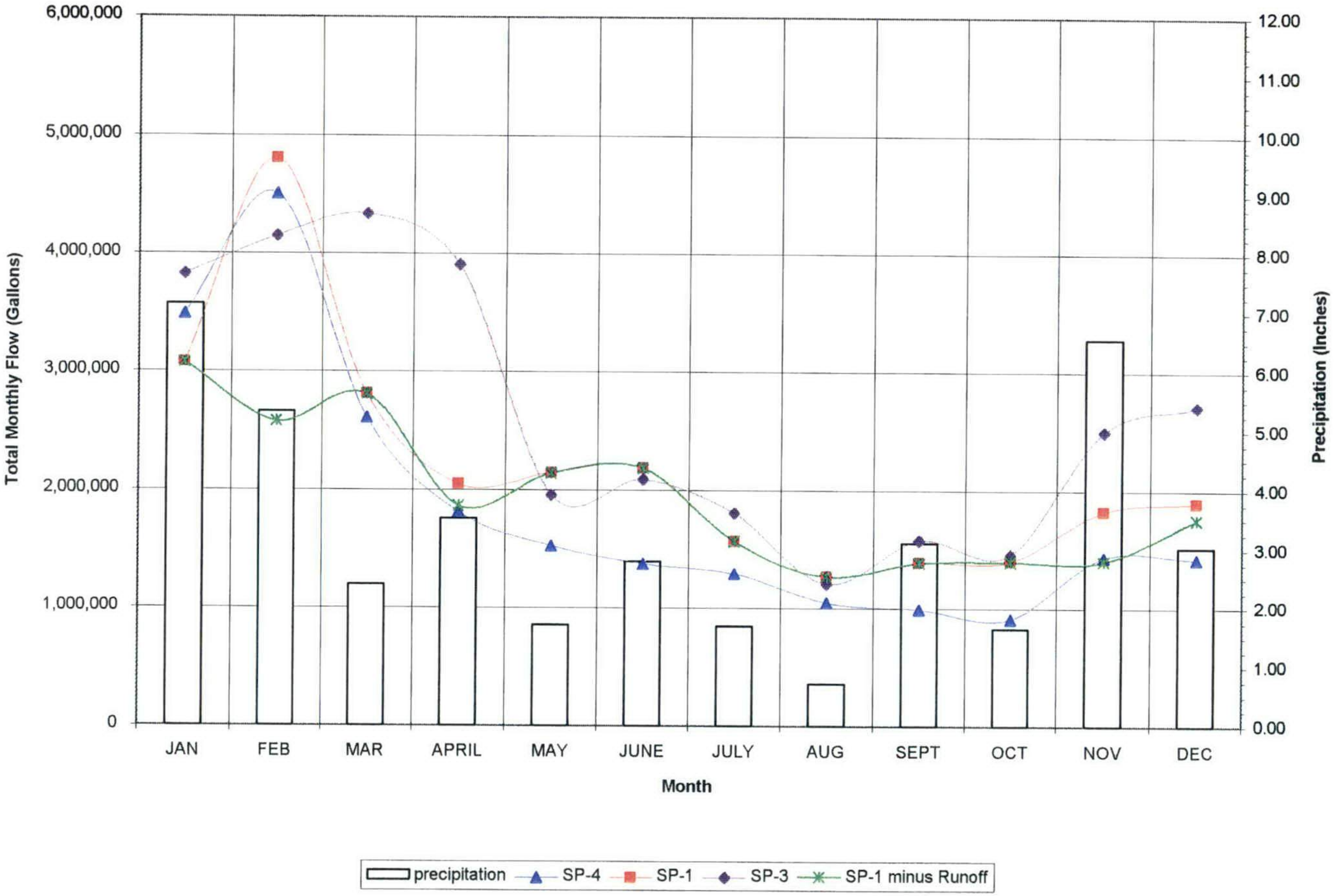
AGI
TECHNOLOGIES

Flows and Precipitation: 1991

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE
21

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95			



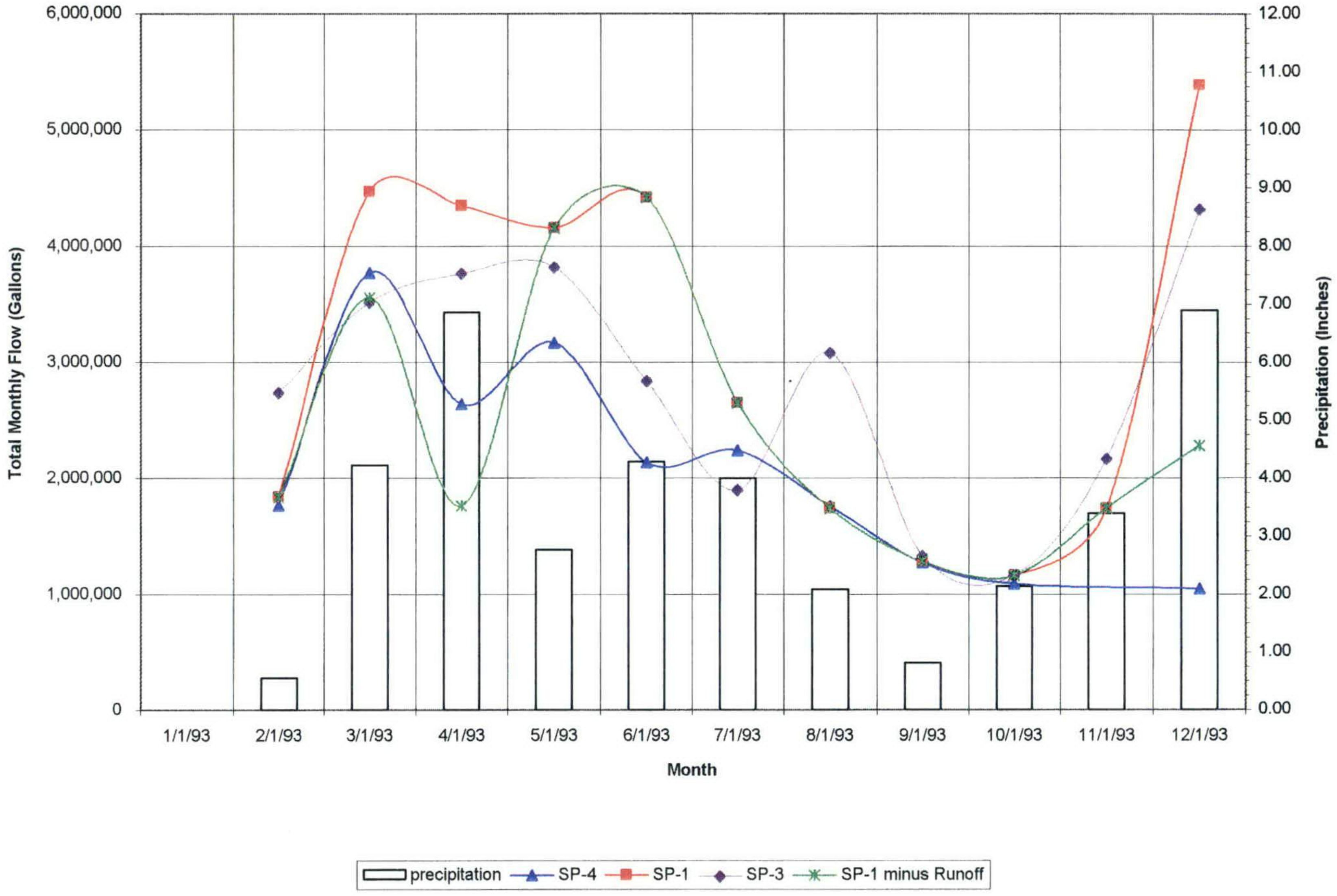
AGI
TECHNOLOGIES

Flows and Precipitation: 1992

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE
22

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95	TMM		



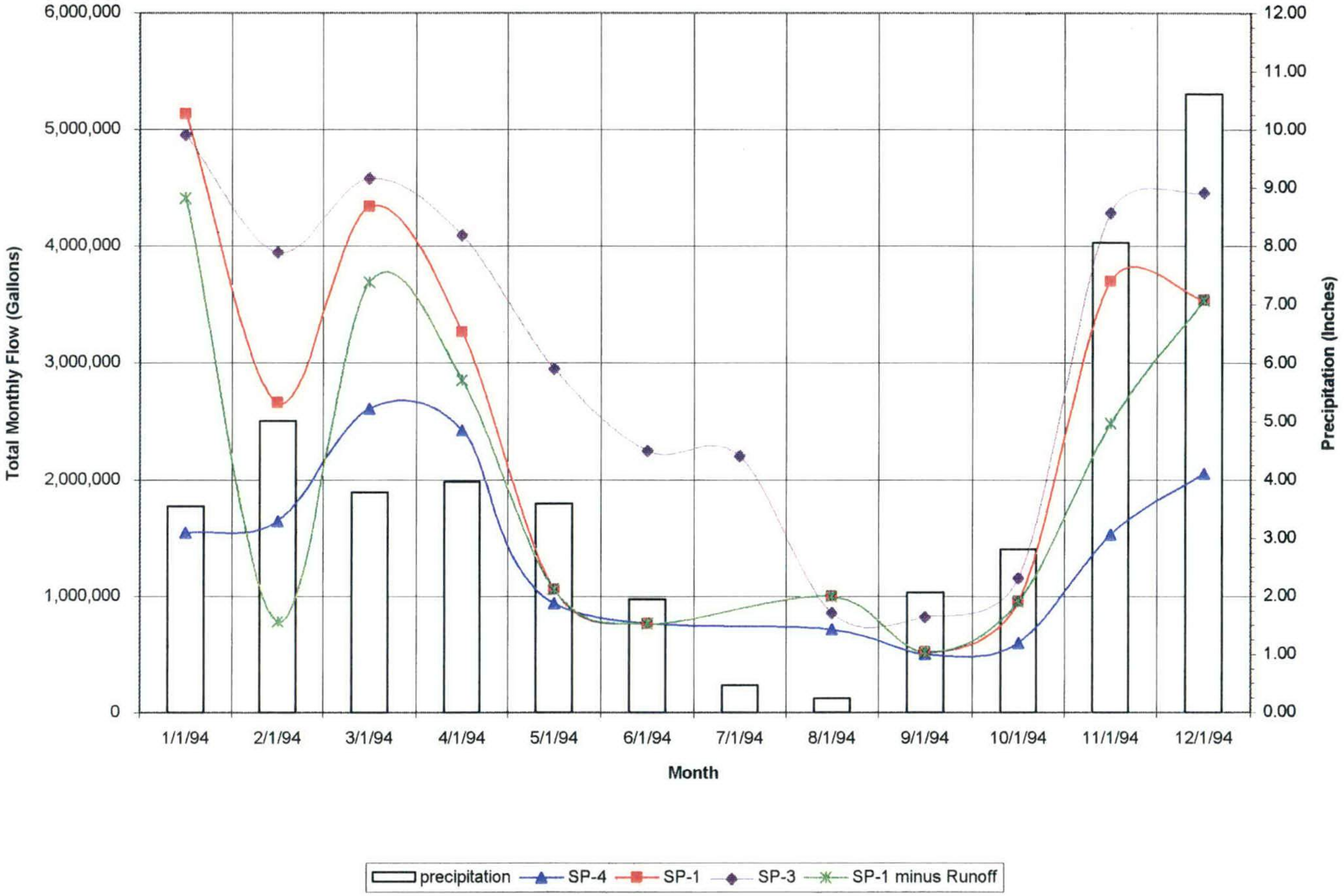
AGI TECHNOLOGIES

Flows and Precipitation: 1993

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE **23**

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95	TMM		



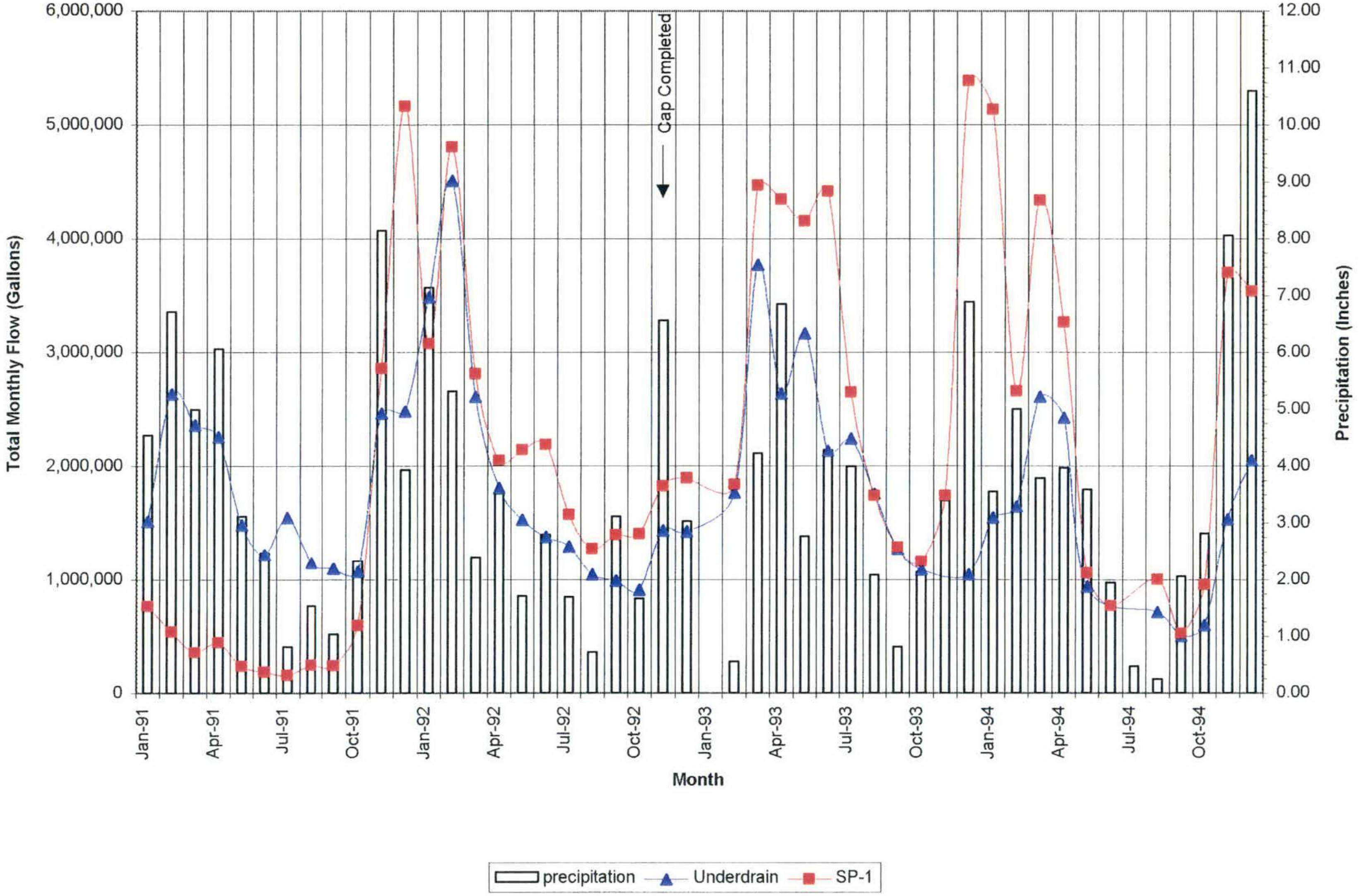
AGI
TECHNOLOGIES

Flows and Precipitation: 1994

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE
24

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95	TMM		

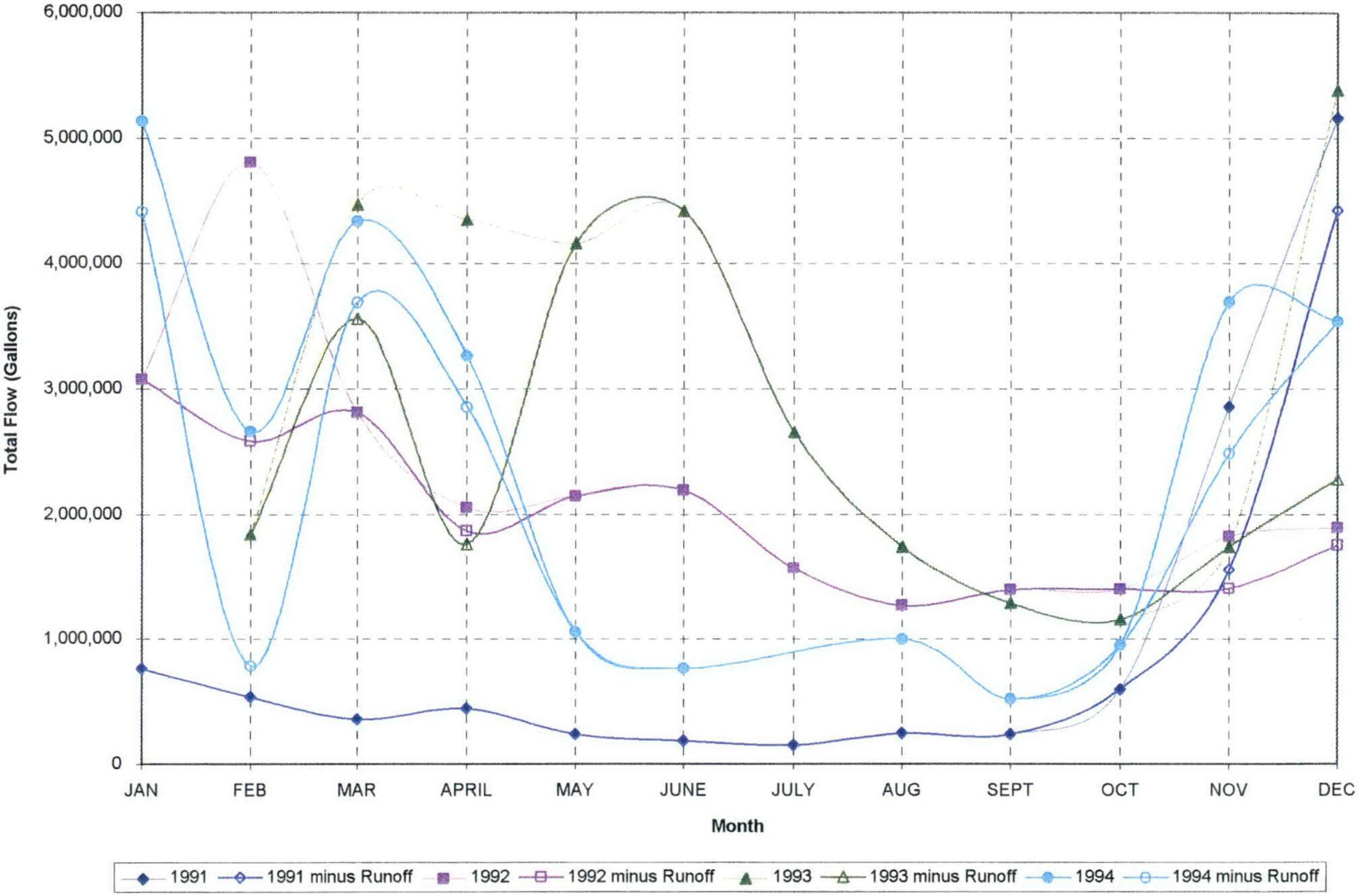


AGI
TECHNOLOGIES

Flows and Precipitation: 1991 through 1994
Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE
25

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95	TMM		



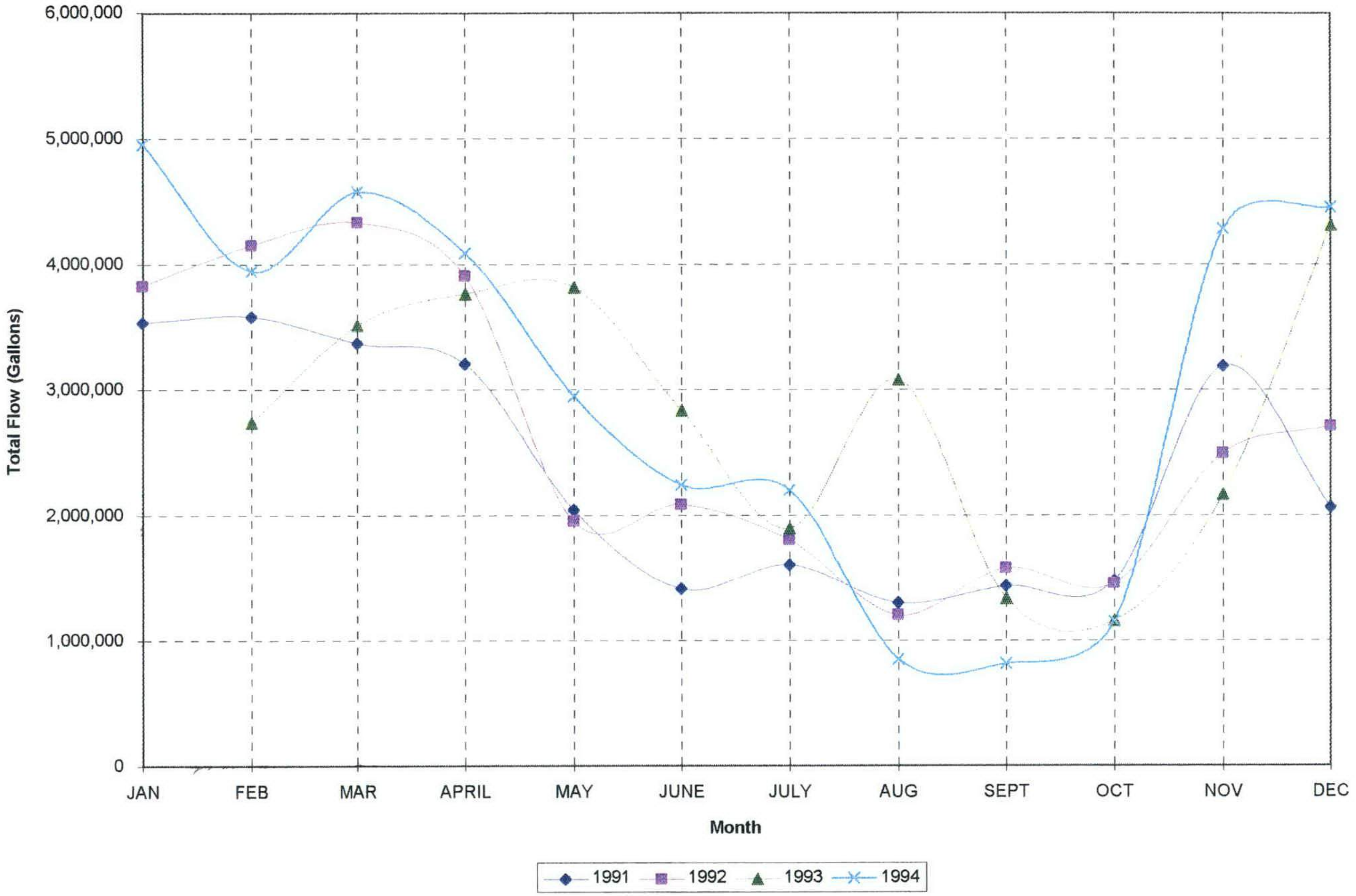
AGI
TECHNOLOGIES

Total Monthly Flows at SP-1 (1991 through 1994)

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE
26

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95	TMM		



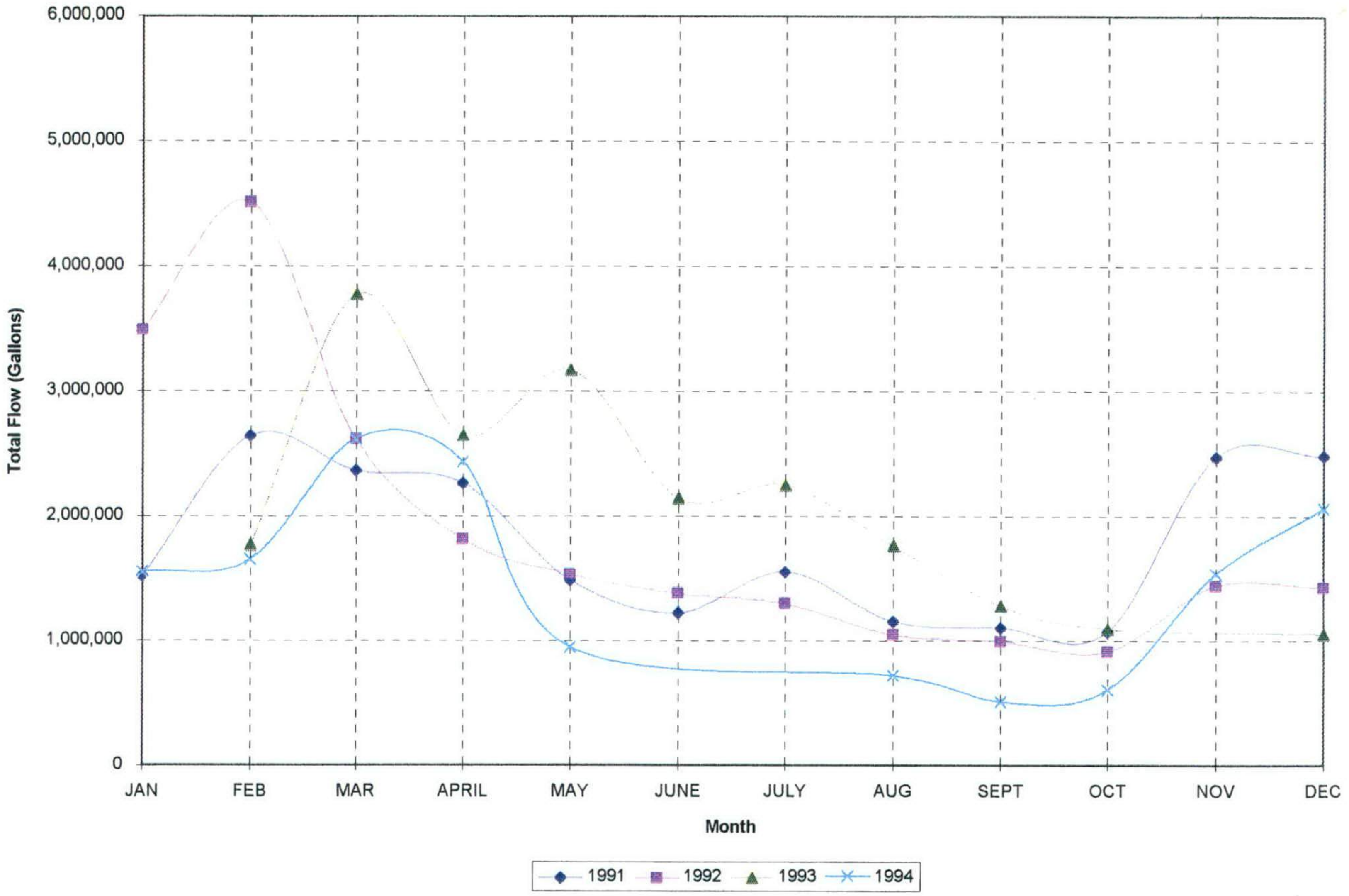
AGI TECHNOLOGIES

Total Monthly Flows at SP-3 (1991 through 1994)

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE
27

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95	TMM		



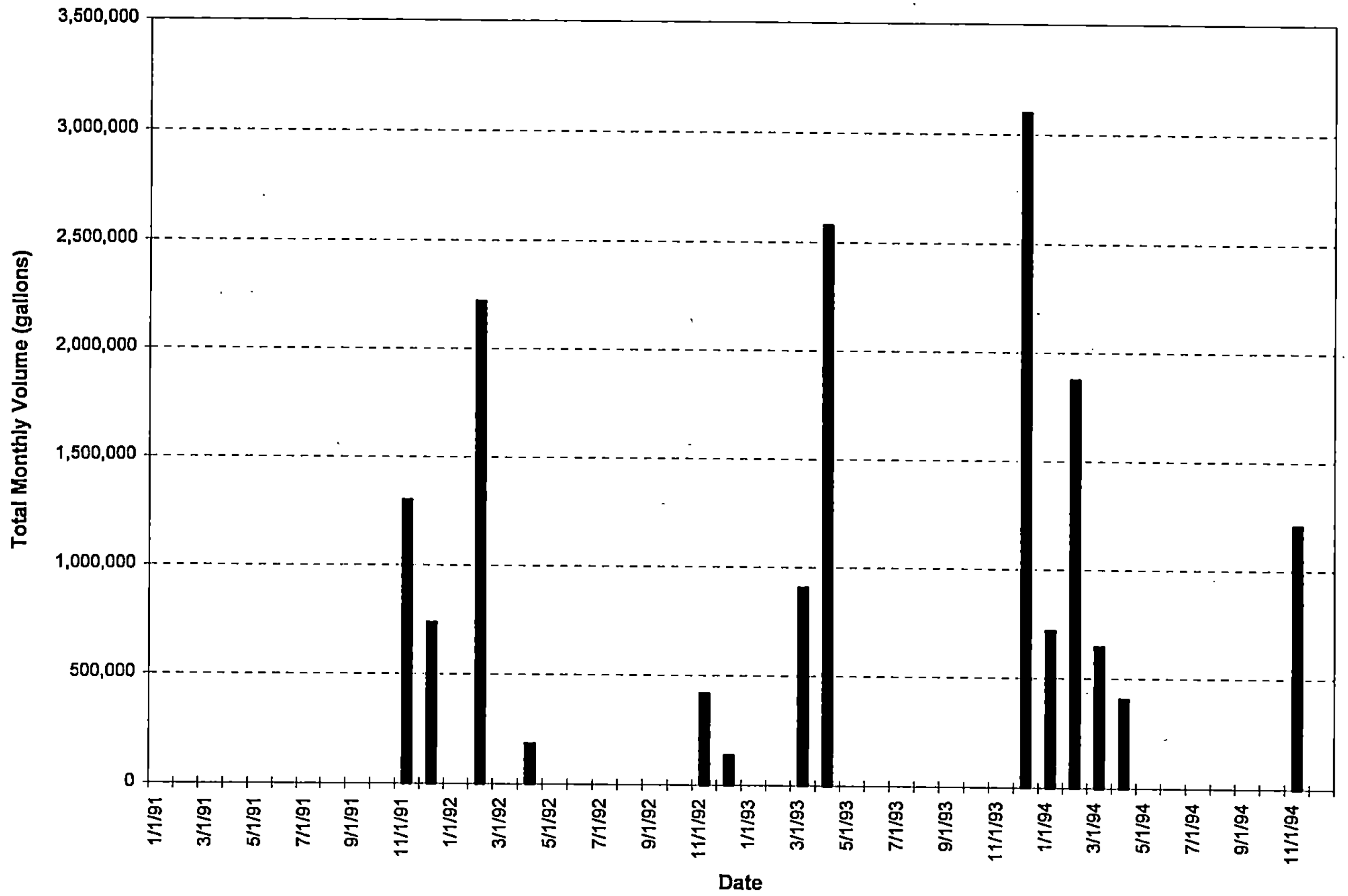
AGI
TECHNOLOGIES

Total Monthly Flows at SP-4 (1991 through 1994)

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE
28

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95	TMM		



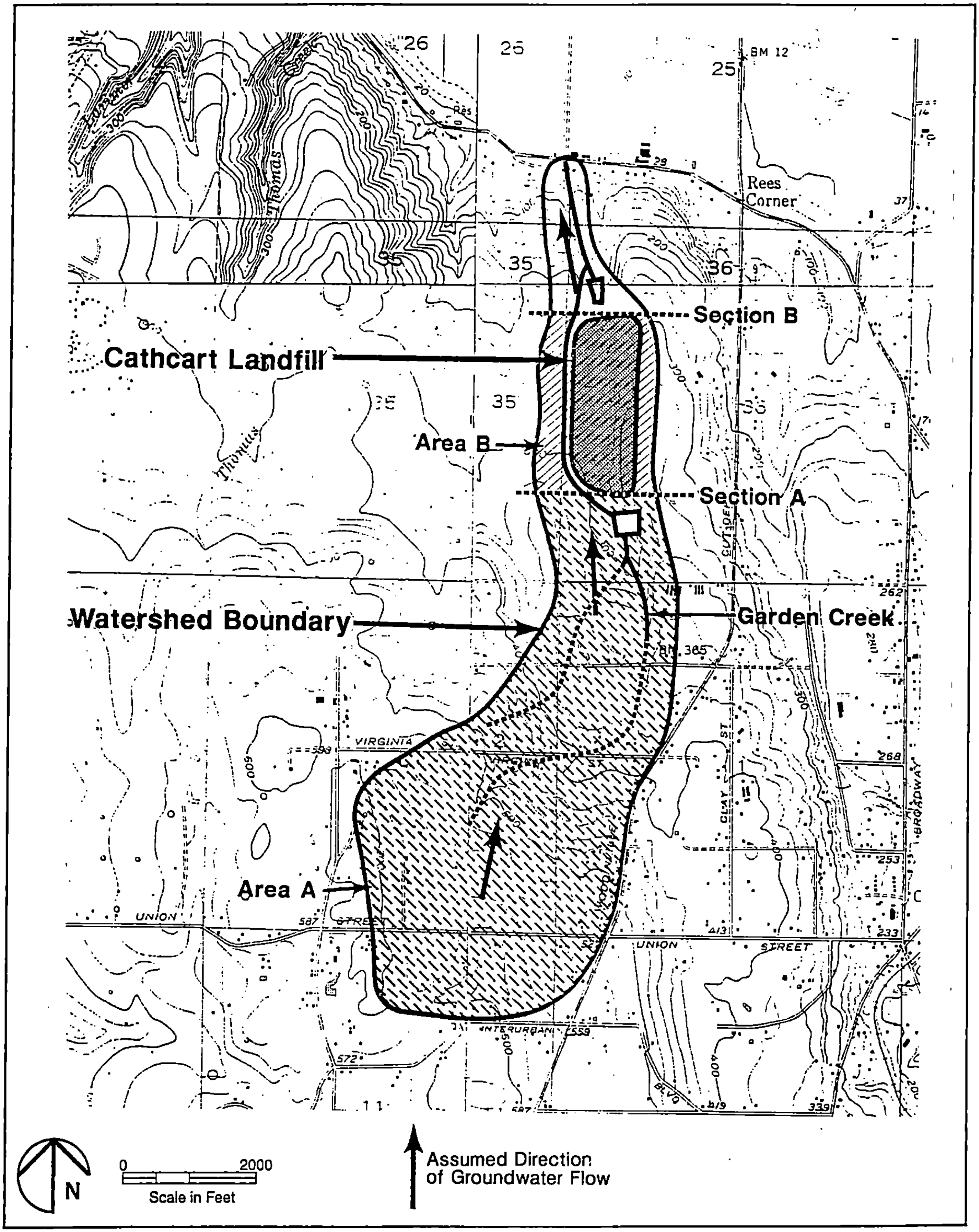
AGI
TECHNOLOGIES

Surface Water Contribution to Total Flows

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE
29

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95			



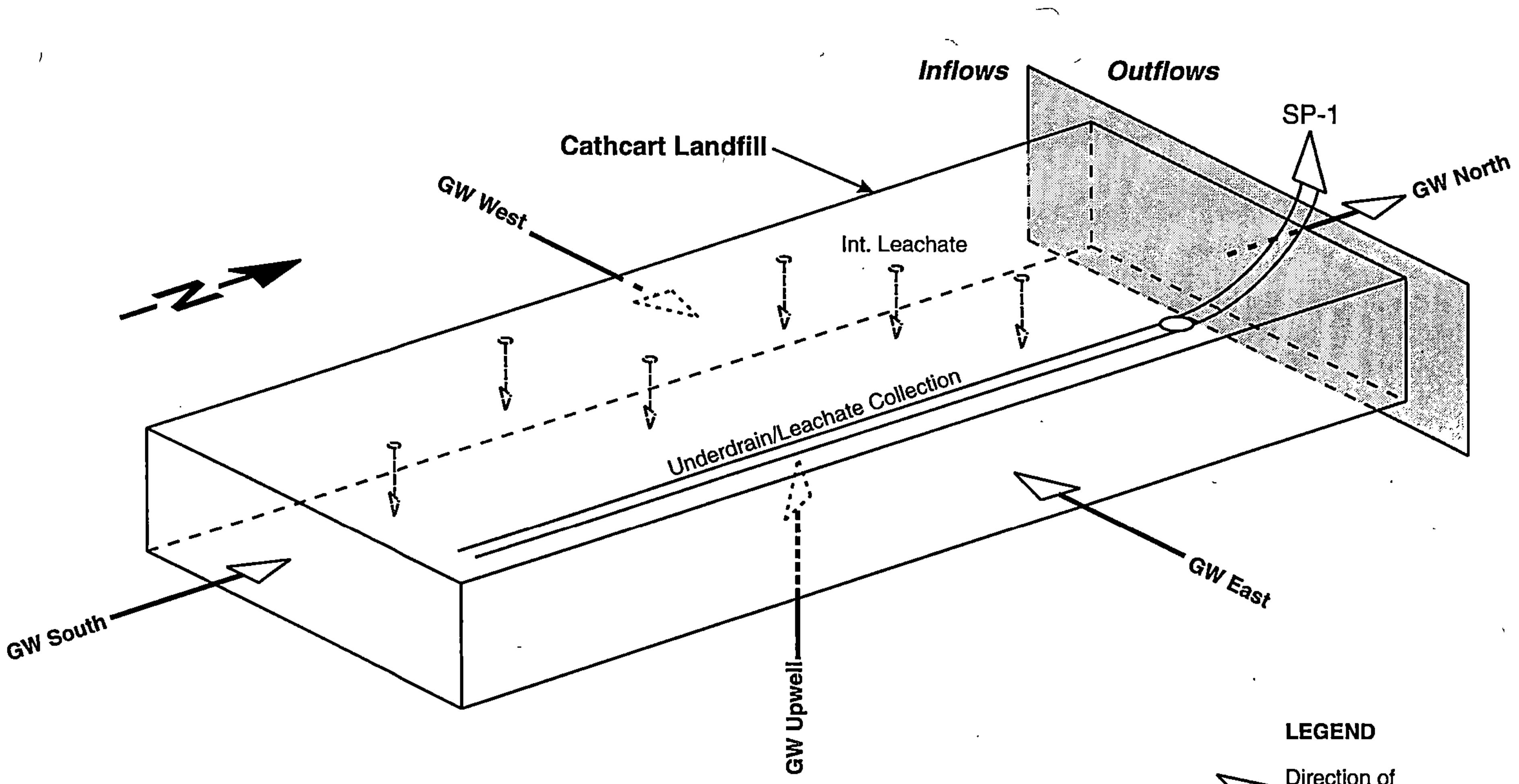
AGI
TECHNOLOGIES

Watershed Balance Areas

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE
30

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	ALW	6 April 95			



LEGEND

Direction of Groundwater Flow

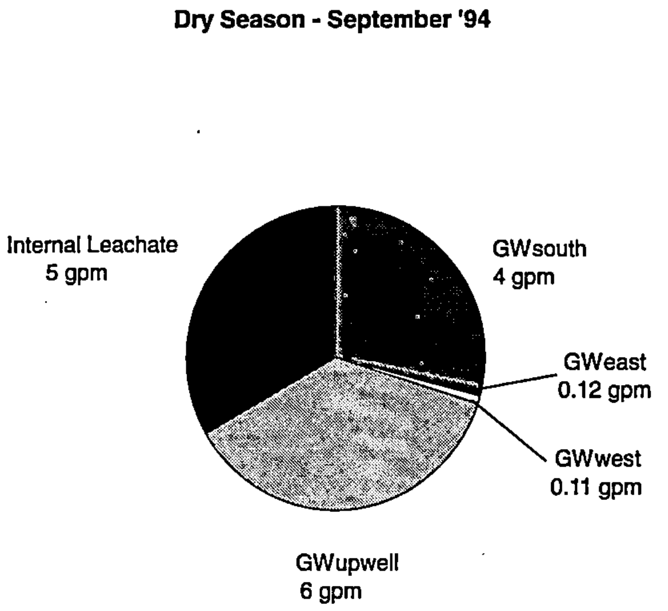
AGI TECHNOLOGIES

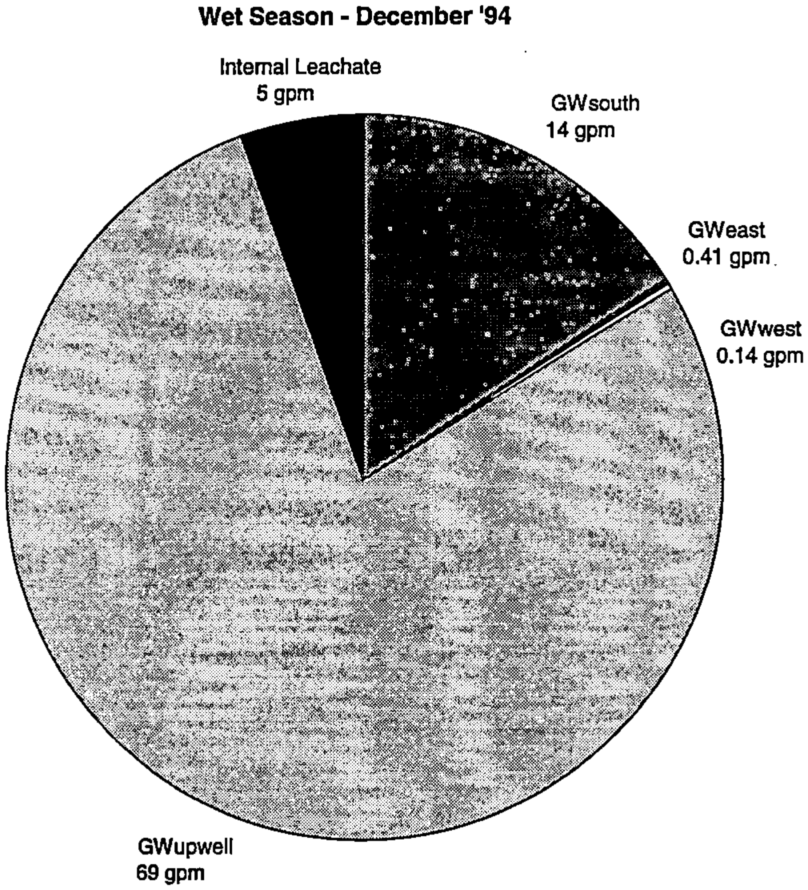
Landfill Hydrologic Budget Schematic

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE **31**

	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
model.cdr	15,512.108	ALW	15 March 95			





AGI
TECHNOLOGIES

Relative Landfill Inflow Magnitudes

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

FIGURE
32

	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
exelchrt.cdr	15,512.108		6 April 95			

AGI
TECHNOLOGIES

APPENDIX A

Historical Timeline For Cathcart Landfill

APPENDIX A

Historical Timeline For Cathcart Landfill

Time Period / Date	Activity
Late 1970s	Landfill designed and constructed
February 1980	Independent investigation of liner integrity performed for Snohomish County (County) due to Washington State Department of Ecology's (Ecology) opinion that liner construction was inadequate. (Raymond Vail, Assoc., *Technical Assistance; Cathcart Sanitary Landfill.*)
Early 1980s	County began groundwater monitoring program.
June 1980	Landfill opened; refuse placement began.
August 29, 1980	Generation of leachate first noted.
September 2, 1980	Sampling indicated presence of leachate in site surface water drainage system.
September 1980	Based on September 2, 1980 results, routine sampling initiated.
November 20, 1980	Sufficient sampling data gathered to indicate contamination of the underdrain with leachate. Ecology notified County that it had determined the underdrain flow was contaminated and this constituted a violation of the National Pollutant Discharge Elimination System (NPDES) permit.
December 9, 1980	County again notified by Ecology letter of the continuing problem.
March 5, 1981	Final warning letter issued by Ecology to County requiring: 1) immediate steps to remove impounded leachate; 2) implement operational procedures to allow continual drainage of the landfill leachate collection system into the aerated lagoon; and 3) a written response within 30 days providing a current status report and a time schedule for a permanent solution to the leachate/treatment disposal need.
April 30, 1981	County sent response letter to Ecology indicating operational procedures had been modified to remove impounded leachate from Phase I and to route contaminated surface runoff into the leachate collection system.

Time Period / Date	Activity
May 14, 1981	Routine inspection made to gather water quality samples at the landfill. Leachate still impounded on the liner and leachate collection line plugged; evidence of leachate being discharged into the underdrain through manhole No. 2. *Sphaerotilus*-type growth noted at the outlet from the north holding pond; black sulfide deposits characteristic of anaerobic conditions also noted on the riprap in the channel at this location.
May 15, 1981	Ecology sent letter to County discussing leachate problems.
June 4 and 29, 1981	Sampling and inspection indicate continued discharge of leachate into the lower holding pond, and leachate impounded on the Phase I liner.
August 17, 1981	Ecology issued compliance order DE 81-505.
1981	North leachate treatment lagoon installed.
1981	Leachate drain between Stages 1 and 2 collapsed; 400 feet eventually replaced with thicker (1-inch) HDPE ~~liner pipe~~.
June 19, 1985	Landfill personnel began keeping daily records of leachate flow.
March 1987	Leachate drain videoed; no breaks indicated, but video indicates a weld on one of the joints in Stage 4 failed, causing distortion of the pipe sidewall.
1988	Sludge removed from north leachate lagoon; liner observed to be floating between quarry spalls.
January 1988	County begins limited groundwater extraction program, pumping leachate-impacted groundwater from G-5 to treatment lagoons. This was done to intercept groundwater and keep it from reaching the north pond. Possible sources of groundwater contamination assumed to be landfill leachate or treatment lagoons.
July 12, 1988	County contracted Converse Consultants Northwest to perform preliminary hydrogeologic evaluation; six new groundwater monitoring wells installed.
September 27, 1988	Converse issued *Preliminary Hydrogeologic Study* report.
1989	Underdrain re-routed to pretreatment facility.
February and June 1989	Supplemental contracts awarded to Converse.

Time Period / Date	Activity
February 1989	Landfill personnel began keeping daily records of underdrain flow.
February 1989	W-1 (6-inch) installed with submersible pump to replace G-5.
November 9, 1989	Converse issued *Phase II Hydrogeologic Study* report.
December 1989	Extraction of leachate-impacted groundwater began at W-1.
January 1990	Ecology representatives visited landfill to check locations of existing wells; suggested installation of a new background well.
Spring 1990	Conditional use permit for landfill modified to allow for vertical expansion of the landfill in Stages 3 through 6.
Spring 1990	North leachate lagoon abandoned.
March 1, 1990	Landfill personnel begin recording water levels in north detention pond.
Feb. - Oct. 1990	Field work for water balance conducted.
Aug. - Sept. 1990	New background well (G-15S) installed (contracted September 1990).
Prior to closure measures, 1990	Gas venting/combustion begun.
Aug. - Sept. 1990	North leachate lagoon removed and backfilled.
Aug. - Oct. 1990	North detention pond drained and sediments removed.
November 1, 1990	Pond pumped dry.
Fall 1990	North detention pond improved to handle increased runoff from final closure of Stages 1 and 2.
November 1, 1990	G-5A and W-1, located in fill material adjacent to north detention pond, dry on November 1.
January 1991	Stages 1 through 2 filled, covered, capped, and seeded. Stages 3 through 6 active until June 1992.
January 10, 1991	Converse issued *Cathcart Landfill Water Balance Investigation* report.
Summer 1991	Landfill accepting approximately 1,000 tons of waste per day.

Time Period / Date	Activity
Fall 1991	Golder Associates performed geophysical survey.
December 30, 1991	Converse issued *Phase III Hydrogeologic Study* report.
January 1992	Basketball removed from underdrain.
February 7, 1992	W-2 installation complete; water level at Elevation 200.94.
June 1992	Refuse placement continued as additions to Stages 3, 4, 5, and 6.
June 1992	Landfill closed to refuse placement.
November 1992	Stages 3 through 6 closed and capped (final closure).
August 20, 1992	Golder Associates issued *Geologic Logging, Construction Observation, and Operational Recommendations for Monitoring Wells W-2, G16-S, and Gas Probe GP-5* draft report.
March - June 1993	North Pond pumped into SP-1.
June 1994	W-1 pumped.

APPENDIX B

Garden Creek Weirs

APPENDIX B

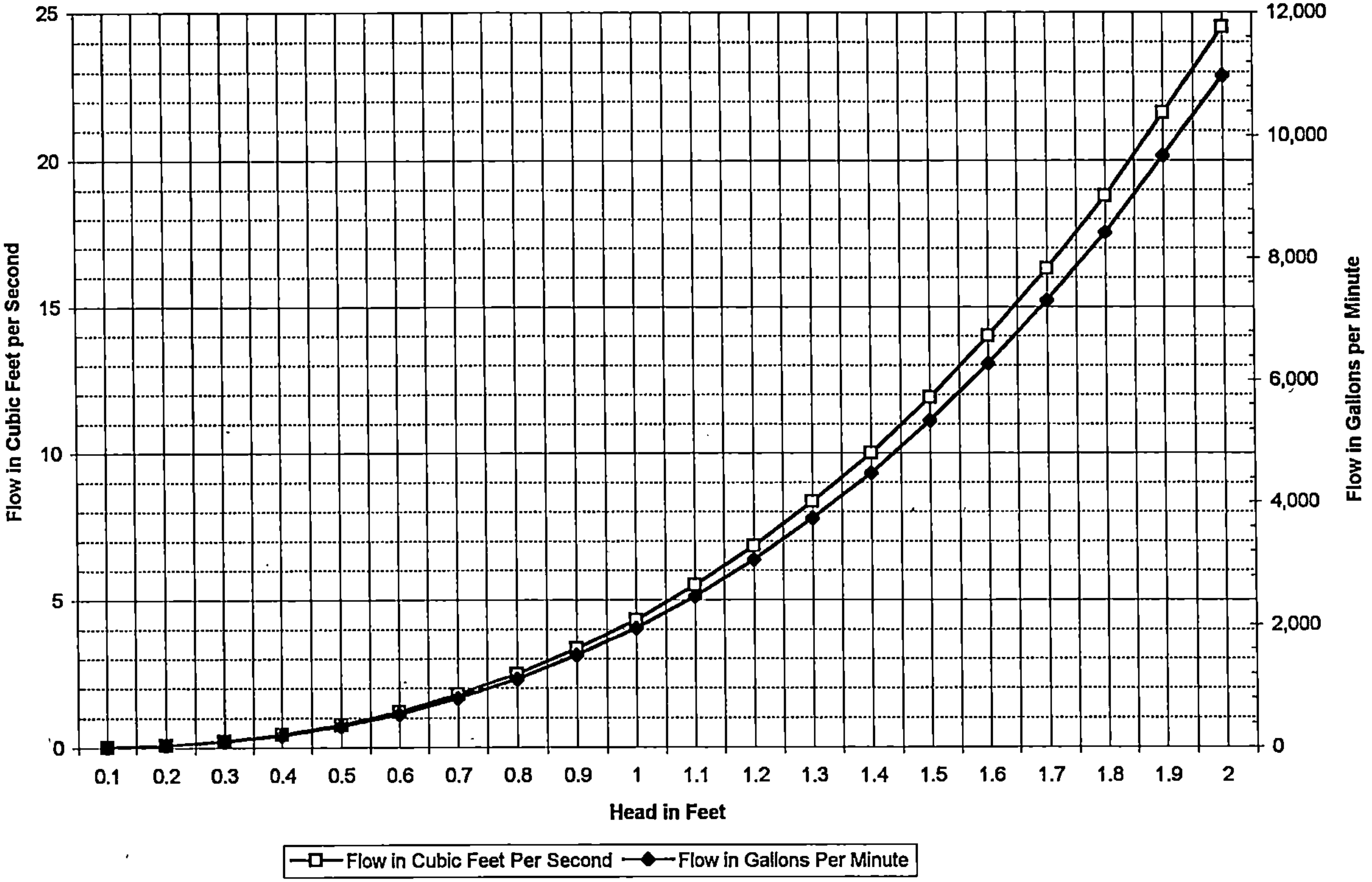
Garden Creek Weirs

Four weirs were installed in Garden Creek along the landfill's west side to quantify Garden Creek flows along the length of the landfill. The weirs were fabricated at AGI prior to installation and installed August 30 through September 5, 1994. Each weir was constructed with the following specifications:

- Material: Marine plywood
- Length: 12 feet
- Height: 4 feet
- Wall Thickness: 3/4 inch
- V-notch Angle: 120 degrees

Weir installation was accomplished by lowering each weir into cuts excavated into the dry channel of Garden Creek. Each weir was then set in place by backfilling around the weir's base and sides with concrete. An existing weir located downstream from the Cathcart Landfill was repaired by erecting it back to a vertical position and setting it in concrete along its sides. The completed weirs were reviewed and approved by Snohomish County Solid Waste Division and Community Development personnel.

Flow in the creek is measured by converting the creeks's upstream pool level read on the weir's staff gauge to flow values. A rating curve for the 120 degree V-notch weirs is shown on **Plate B-1.**



AGI
TECHNOLOGIES

120° V-Notch Weir Flow Rating Curve

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PLATE
B-1

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	6 Mar 95	TMM		

APPENDIX C

Subsurface Investigation Activities and Boring Logs

APPENDIX C

Subsurface Investigation Activities and Boring Logs

DRILLING

Drilling was performed by Layne Environmental Services of Tacoma, Washington using an AP 1000 percussion drill rig equipped with dual-wall 6-inch inside-diameter steel conductor casing. Drilling activities were performed May 2 through May 5, 1994. AGI Technologies (AGI) characterized geologic conditions by:

- Examining drill cuttings during removal from the borehole.
- Observing the resistance to drilling as indicated by drill rate and behavior.
- Collecting soil samples at 5-foot intervals using a modified California Sampler (2.5-inch inside-diameter). The sampler was driven with a 140-pound hammer dropped from a height of approximately 30 inches.

All boreholes were logged by an AGI geologist, who examined and classified the materials encountered, obtained representative soil samples, and recorded pertinent information, including soil sample depths, stratigraphy, and groundwater occurrence. Soils were classified in the field in accordance with the Unified Soil Classification System (USCS) and Physical Properties Criteria for Rock Description, which are presented on **Plates C-1** and **C-2**. Following completion of drilling, the borings were converted to groundwater piezometers. Typical piezometer construction is shown on **Plate C-3**. Piezometer construction is further discussed below.

Soil samples were sealed to limit moisture loss, labeled, and transported to our laboratory for further geologic classification. Boring logs were modified where needed to reflect the laboratory sample examination. Boring logs are presented on **Plates C-4** through **C-11**. The stratification lines shown on the individual logs represent the approximate boundaries between soil types; actual transitions may be either more gradual or more abrupt. The conditions depicted are for the dates and locations indicated only, and may not be representative of conditions at other locations and times.

Ambient air quality at borehole locations was monitored to ensure volatile organic compound (VOC) vapors and combustible gases did not exceed action levels established in the site Health and Safety Plan. Prior to drilling, an explosimeter was used to monitor air quality and combustible gases at each drill site. During drilling, ambient air quality and combustible gas parameters were measured near the top of the borehole and in the worker's breathing area.

The drill rig, conductor casing, and downhole sampling tools were decontaminated with a high-pressure steam cleaner prior to drilling each boring. Steam cleaning was performed at Snohomish County's (County) wash rack and oil/water separator located at Cathcart Landfill. Soil sampling equipment was typically decontaminated between sampling intervals by washing it in a solution of phosphate-based soap and tap water followed by a tap water rinse when needed.

PIEZOMETER INSTALLATION

Borings PZ-1 through PZ-7 and G-24 were advanced to depths of 45 to 70 feet below ground surface (bgs). One piezometer each was installed in borings PZ-1 through PZ-7 as the conductor casing was extracted after reaching total boring depth. PZ-1 through PZ-4 screens were set in the Qtb Aquifer, and PZ-5 through PZ-7 screens were set in the Tertiary sandstone. The piezometers were constructed in accordance with Washington Administrative Code (WAC), Chapter 173-160 *Standards for Resource Protection Wells* (March 13, 1990). Typical piezometer construction details are presented on Plate C-3. Piezometer construction details are presented on the boring logs (Plates C-4 through C-11).

General procedures for piezometer construction are summarized below.

- Piezometers were constructed of 1-inch-diameter, flush-threaded, coupled Schedule 80 blank PVC riser pipe and machine-slotted (0.010-inch slot) screen with a bottom cap. The length of the well assembly (PVC riser, screen, and end cap) was measured and recorded prior to installation. The blank riser pipe extends from the top of the screen to approximately 1/2 foot below ground surface.

- Colorado 10-20 silica sand was used to fill the boring annulus from the bottom of the screen to 2 to 3 feet above the top of the screen. During installation, depths to the piezometer construction materials were measured frequently with a precleaned, weighted measuring tape to prevent overfilling or bridging inside the drill conductor casing.

- Piezometers were sealed with bentonite chips and a bentonite-based grout to form an annular hydraulic seal above the screen sand pack.

- Protective well monuments with locking caps were installed over the PVC well casings and set in a 4-foot-square by 1/2-foot-thick concrete ground pad. No piezometers are in access and perimeter roads.

CUTTINGS AND DEVELOPMENT WATER DISPOSAL

Soil cuttings generated during drilling were placed on visqueen and left at each drill site. The cuttings were subsequently removed by the County and transported to the landfill stockpile area.

UNIFIED SOIL CLASSIFICATIONS SYSTEM

MAJOR DIVISIONS				TYPICAL NAMES
COARSE GRAINED SOILS More than half is larger than No. 200 Sieve	**GRAVELS** More than half coarse fraction is larger than No. 4 sieve size	Clean gravels with little or no fines	GW	Well graded gravels, gravel-sand mixtures
			GP	Poorly graded gravels, gravel-sand mixtures
		Gravels with over 12% fines	GM	Silty Gravels, poorly graded gravel-sand-silt mixtures
			GC	Clayey gravels, poorly graded gravel-sand-clay mixtures
	SANDS More than half coarse fraction is smaller than No. 4 sieve size	Clean sands with little or no fines	SW	Well graded sands, gravelly sands
			SP	Poorly graded sands, gravelly sands
		Sands with over 12% fines	SM	Silty sand, poorly graded sand-silt mixtures
			SC	Clayey sands, poorly graded sand-clay mixtures
FINE GRAINED SOILS More than half is smaller than No. 200 Sieve	**SILTS AND CLAYS** Liquid limit less than 50		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
			OL	Organic clays and organic silty clays of low plasticity
	SILTS AND CLAYS Liquid limit greater than 50		MH	Inorganic silts, micaceous or diatomacious fine sandy or silty soils, elastic silts
			CH	Inorganic clays of high plasticity, fat clays
			OH	Organic clays of medium to high plasticity, organic silts
HIGHLY ORGANIC SOILS			PT	Peat and other highly organic soils

SAMPLE

- ■ "Undisturbed"
- ▨ Bulk/Grab
- ◫ Not Recovered
- ▦ Recovered, Not Retained

CONTACT BETWEEN UNITS

- —— Well Defined Change
- ⟋ Gradational Change
- - - - Obscure Change
- ▬ End of Exploration

PHYSICAL PROPERTY TESTS

Consol - Consolidation
LL - Liquid Limit
PL - Plastic Limit
Gs - Specific Gravity
SA - Size Analysis
TxS - Triaxial Shear
TxP - Triaxial Permeability
Perm - Permeability
Po - Porosity
MD - Moisture/Density
DS - Direct Shear
VS - Vane Shear
Comp - Compaction

UU - Unconsolidated, Undrained
CU - Consolidated, Undrained
CD - Consolidated, Drained

BLOWS PER FOOT

Hammer is 140 pounds with 30-inch drop, unless otherwise noted

S - SPT Sampler (2.0-Inch O.D.)
T - Thin Wall Sampler (2.8-Inch Sample)
H - Split Barrel Sampler (2.4-Inch Sample)

MOISTURE DESCRIPTION

Dry - Considerably less than optimum for compaction
Moist - Near optimum moisture content
Wet - Over optimum moisture content
Saturated - Below water table, in capillary zone, or in perched groundwater

AGI
TECHNOLOGIES

Soil Classification/Legend

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PLATE
C1

	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
soilcls.cdr	15,512.108	ALW	6 March 95	TMM		

I **CONSOLIDATION OF SEDIMENTARY ROCKS;** usually determined from unweathered samples. Largely dependent on cementation.

U = unconsolidated
P = poorly consolidated
M = moderately consolidated
W = well consolidated

II BEDDING OF SEDIMENTARY ROCKS

Splitting Property	Thickness	Stratification
Massive	Greater than 4.0 ft.	very thick bedded
Blocky	2.0 to 4.0 ft.	thick-bedded
Slabby	0.2 to 2.0 ft.	thin-bedded
Flaggy	0.05 to 0.2 ft.	very thin-bedded
Shaly or platy	0.01 to 0.05 ft.	laminated
Papery	less than 0.01 ft.	thinly laminated

III FRACTURING

Intensity	Size of Pieces in Feet
Very little fractured	Greater than 4.0
Occasionally fractured	1.0 to 4.0
Moderately fractured	0.5 to 1.0
Closely fractured	0.1 to 0.5
Intensely fractured	0.05 to 0.1
Crushed	Less than 0.05

IV HARDNESS

1. **Soft** — Reserved for plastic material alone
2. **Low hardness** — can be gouged deeply or carved easily with a knife blade
3. **Moderately hard** — can be readily scratched by a knife blade; scratch leaves a heavy trace of dust and is readily visible after the powder has been blown away.
4. **Hard** — can be scratched with difficulty; scratch produces little powder and is often faintly visible.
5. **Very hard** — cannot be scratched with knife blade; leaves a metallic streak.

V STRENGTH

1. **Plastic** or very low strength
2. **Friable** — crumbles easily by rubbing with fingers
3. **Weak** — An unfractured specimen of such material will crumble under light hammer blows.
4. **Moderately strong** — Specimen will withstand a few heavy hammer blows before breaking.
5. **Strong** — Specimen will withstand a few heavy ringing hammer blows and will yield with difficulty only dust and small flying fragments.
6. **Very strong** — Specimen will resist heavy ringing hammer blows and will yield with difficulty only dust and small flying fragments.

VI **WEATHERING** — The physical and chemical disintigration and decomposition of rocks and minerals by natural processes such as oxidation, reduction, hydration, solution, carbonation, and freezing and thawing.

D. **Deep** — Moderate to complete mineral decomposition; extensive disintegration; deep and thorough discoloration; many fractures, all extensively coated or filled with oxides, carbonates and/or clay or silt.
M. **Moderate** — Slight change or partial decomposition of minerals; little disintegration; cementation little to unaffected. Moderate to occasionally intense discoloration. Moderately coated fractures.
L. **Little** — No megascopic decomposition of minerals; little or no effect on normal cementation. Slight and intermittent, or localized discoloration. Few stains on fracture surfaces.
F. **Fresh** — Unaffected by weathering agents. No disintegration or discoloration. Fractures usually less numerous than joints.

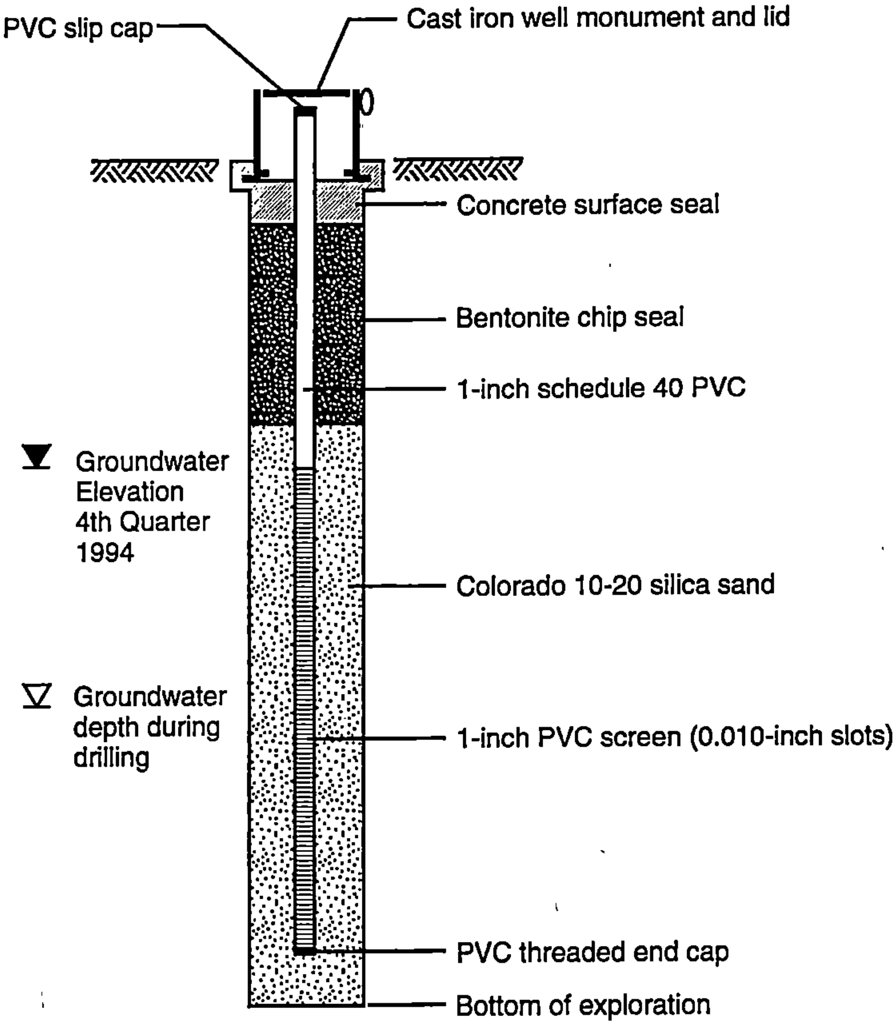
AGI
TECHNOLOGIES

Physical Properties Criteria for Rock Description

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PLATE
C2

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	JFL		TMM		



AGI TECHNOLOGIES

Monitoring Well Construction

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

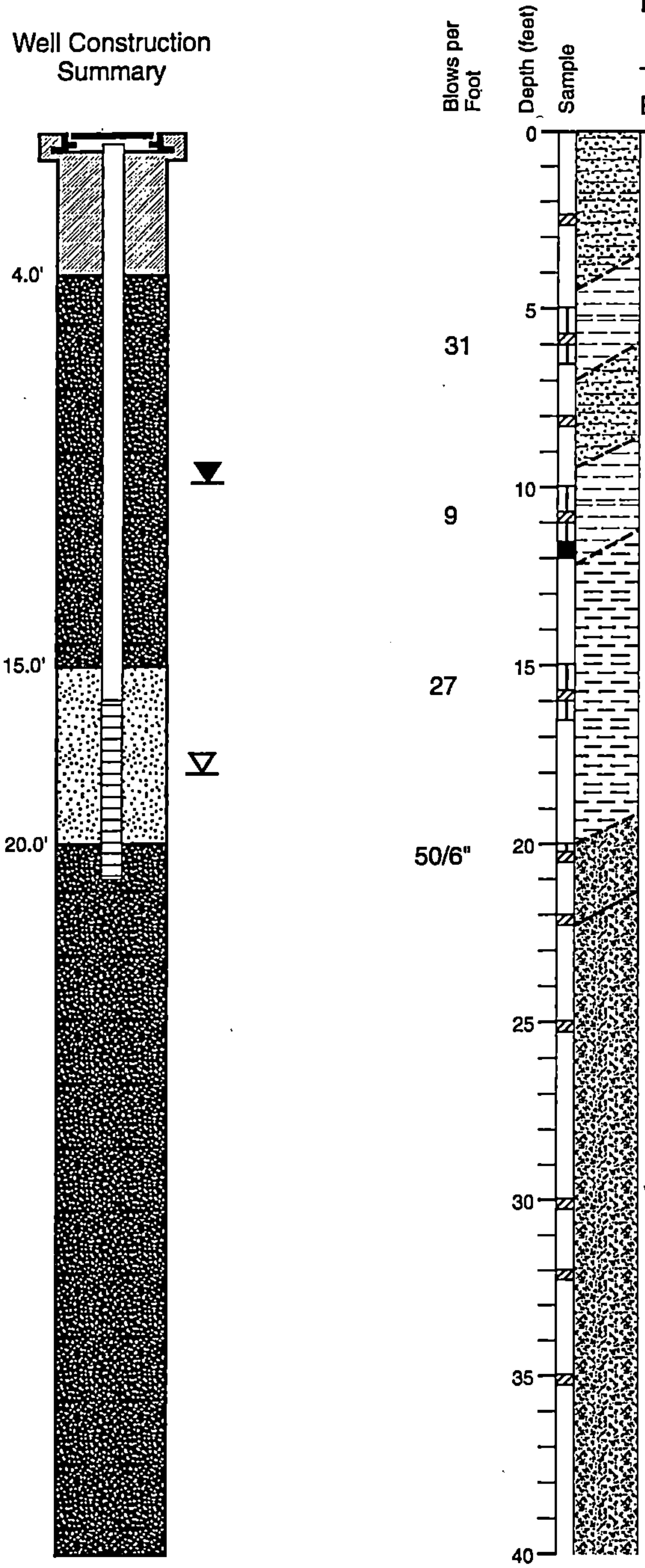
PLATE **C3**

	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
wellcons.cdr	15,512.108	DFF	10 May 95	TMM		

Equipment AP 1000 Dual Wall

Top of Casing Elevation 318.84 feet

Start Date 5/5/94



BROWN SILTY SAND (SM) moist; with some gravel (Fill).

BROWN GRAY SANDY SILT (ML) very stiff, moist; with some gravel and wood fragments (Fill).

BROWN GRAY SILTY SAND (SM) moist (Fill).

BROWN SANDY SILT (ML) medium stiff, moist; with some sand and gravel and a trace of organics.

BROWN SILT (MH) elastic, wet; with some sand and gravel.

Becomes reddish brown, very stiff, with a trace of gravel.

RED BROWN SILTSTONE, low hardness, moist; weak, deeply oxidized.

DARK GRAY SANDY SILTSTONE, well consolidated, flaggy, moderately hard, weak, fresh to little weathered, sand is very fine grained.

Becomes well consolidated, platey.

With some sand and a trace of shells.

AGI TECHNOLOGIES

Log of Well PZ-1 (0-40')

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

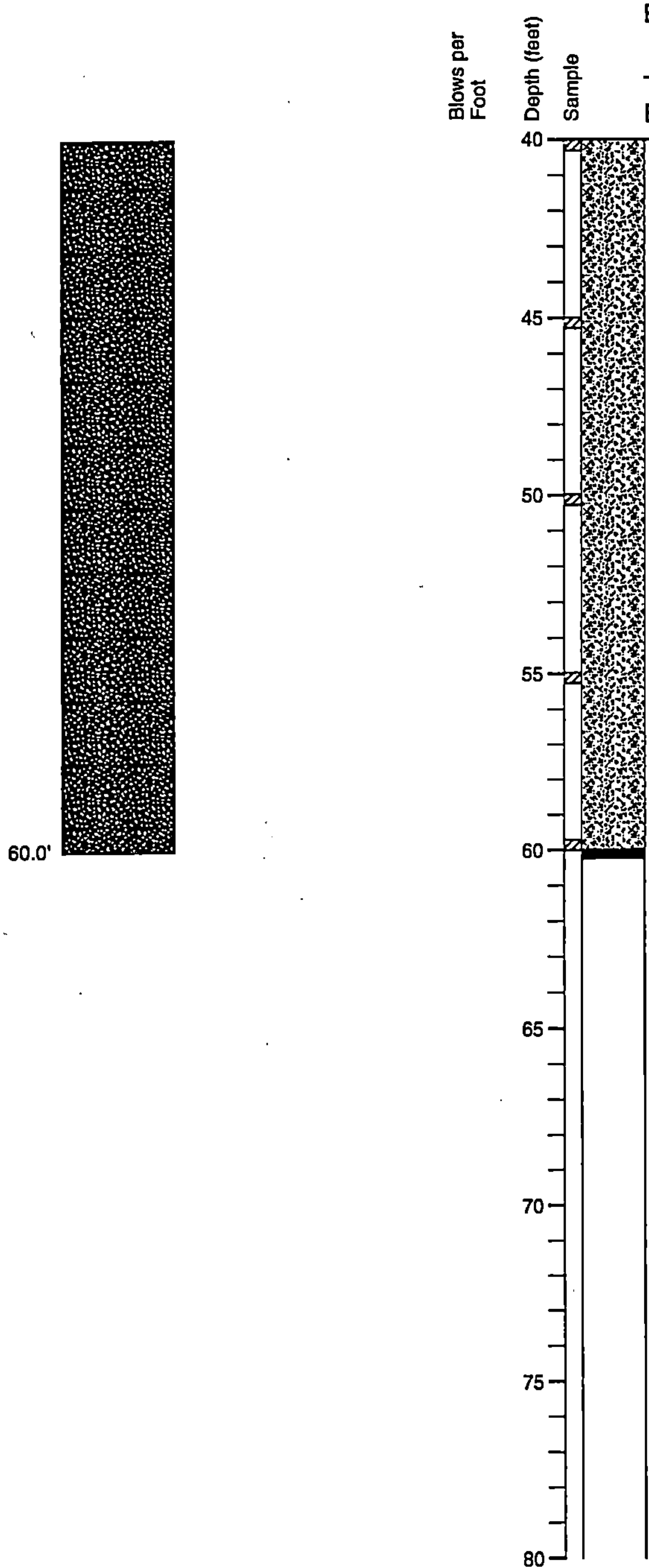
PLATE **C4a**

	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
512108mw.cdr	15,512.108	JFL/ALW	4 April 95			

Equipment AP 1000 Dual Wall

Top of Casing Elevation 318.84 feet

Start Date 5/5/94



Boring terminated on 5/5/94.
Groundwater encountered at 18 feet during drilling.

AGI TECHNOLOGIES

Log of Well PZ-1 (40-60')

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PLATE **C4b**

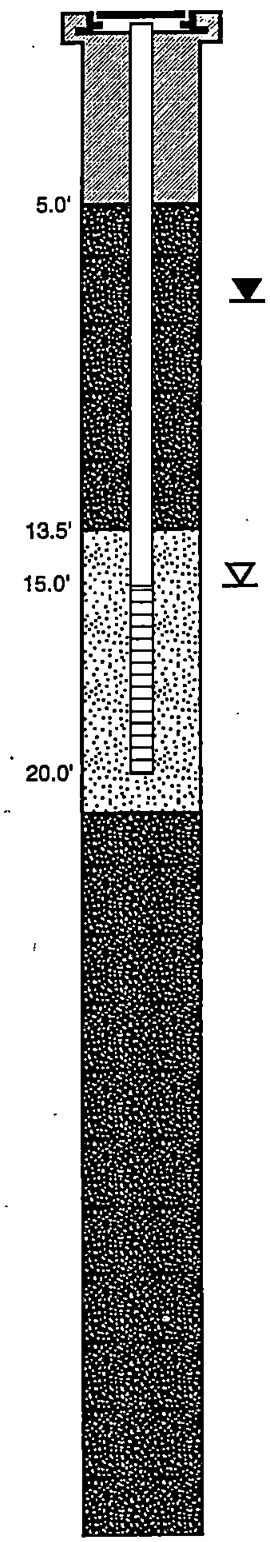
	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
512108mw.cdr	15,512.108	JFL/ALW	4 April 95	TMM		

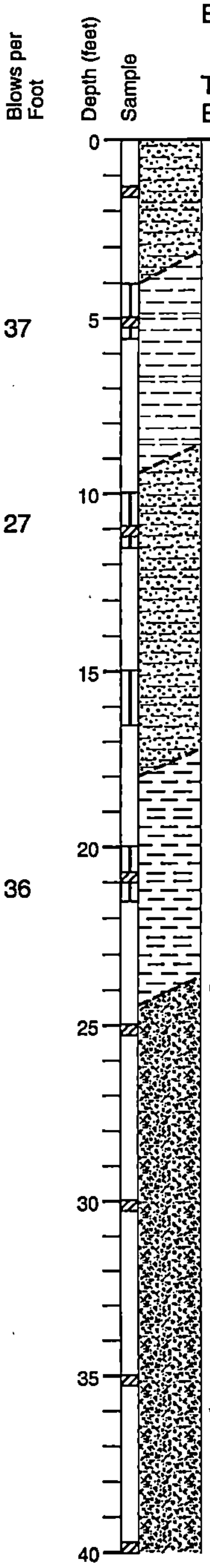
Equipment AP 1000 Dual Wall

Top of Casing Elevation 319.63 feet

Start Date 5/4/94

Well Construction Summary





BROWN SILTY SAND (SM) moist; with some gravel (Fill).

GRAY BROWN SANDY SILT (ML) very stiff, moist; with some gravel and a trace of organics (Fill).

GRAY BROWN SILTY SAND (SM) medium dense, moist; with some gravel and a trace of wood fragments (Till).

BROWN SANDY SILT (MH) elastic, wet; with some gravel.

GRAY SANDY SILTSTONE, well consolidated, flaggy, moderately hard, weak, fresh, fine to medium grained sand.

With a trace of wood fragments.

AGI TECHNOLOGIES

Log of Well PZ-2 (0-40')

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

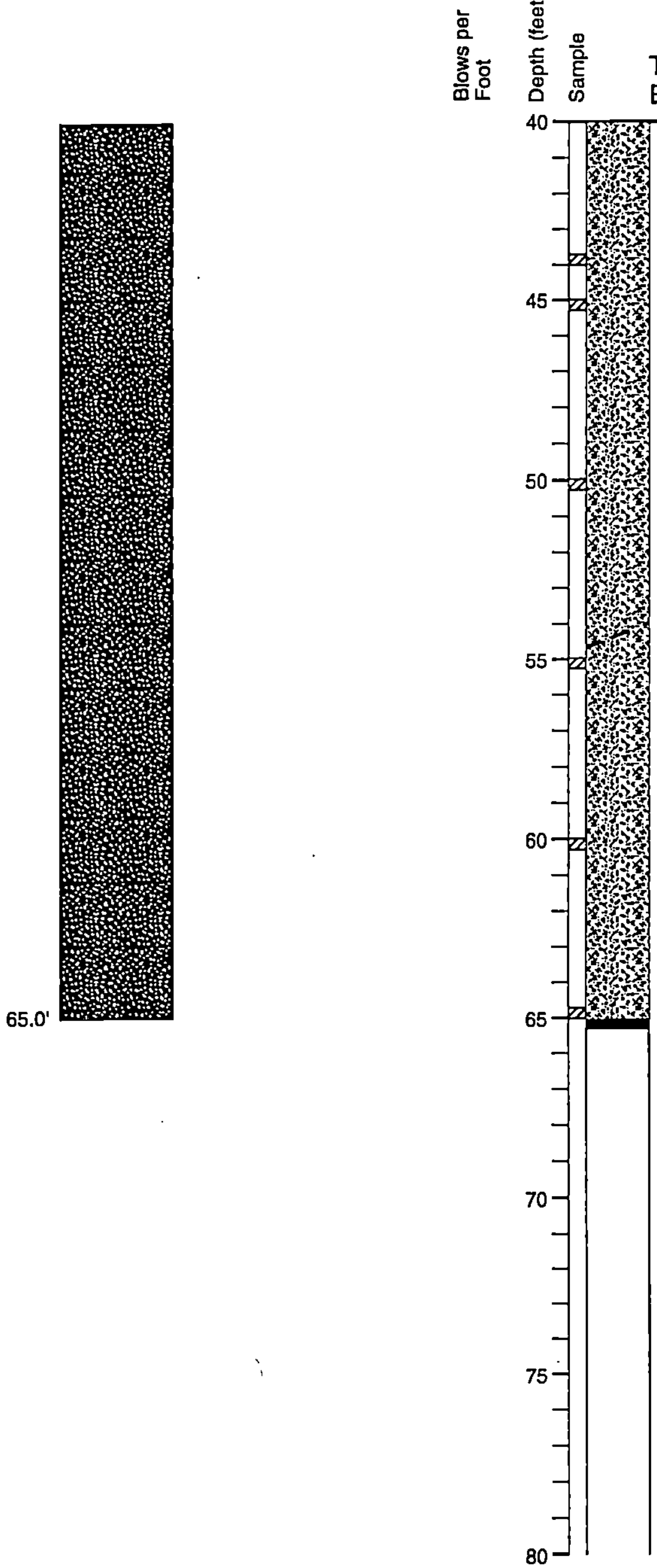
PLATE **C5a**

	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
512108mw.cdr	15,512.108	JFL/ALW	4 April 95	TMM		

Equipment AP 1000 Dual Wall

Top of Casing Elevation 319.63 feet

Start Date 5/4/94



With shell fragments.

With a trace of organics and wood fragments.

DARK GRAY SANDY SILTSTONE, well consolidated, flaggy, moderately hard, fresh, fine to medium sand.

Boring terminated on 5/5/94.
Groundwater encountered at 15 feet during drilling.

AGI TECHNOLOGIES

Log of Well PZ-2 (40-65')

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

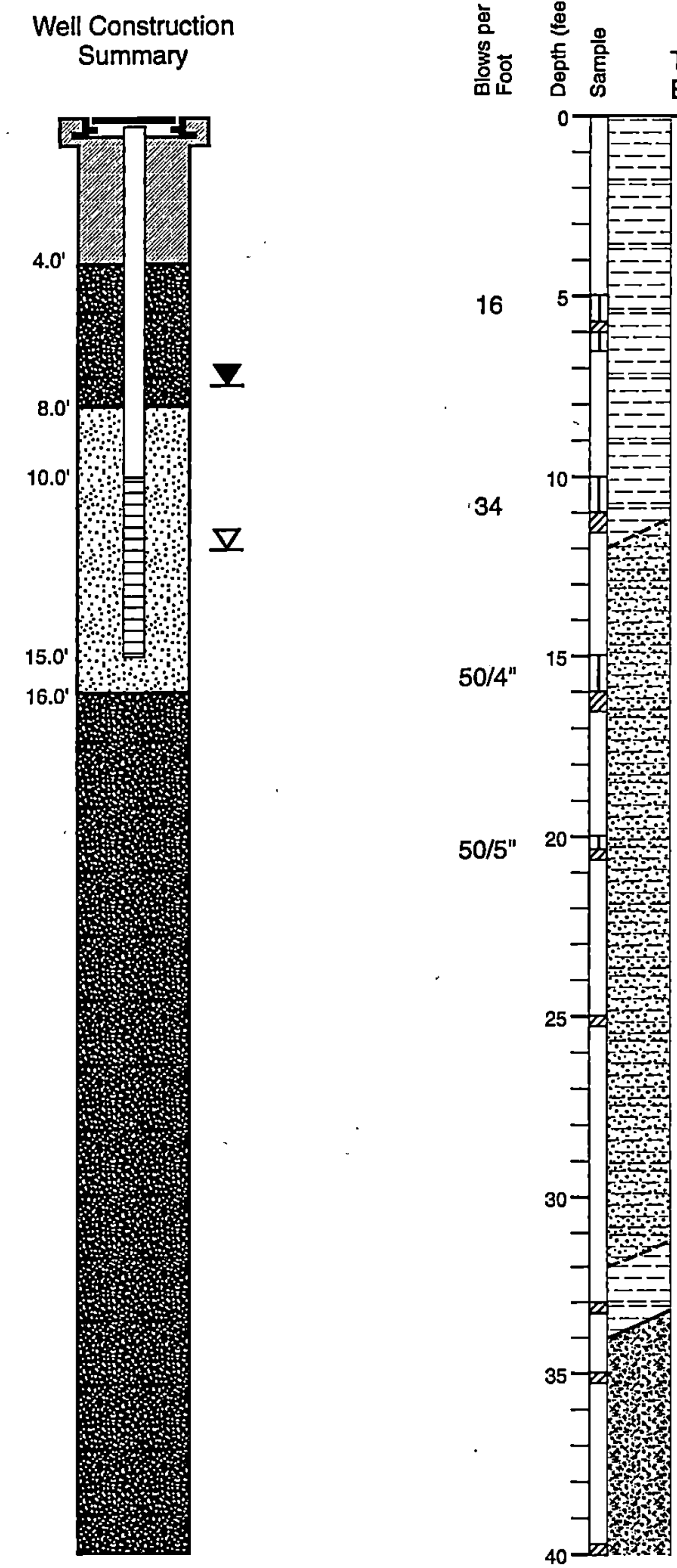
PLATE **C5b**

	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
512108mw.cdr	15,512.108	JFL/ALW	4 April 95	TMM		

Equipment AP 1000 Dual Wall

Top of Casing Elevation 324.18 feet

Start Date 5/4/94



BROWN SANDY SILT (ML) stiff, moist; with some gravel and a trace of organics (Fill).

Becomes red brown, saturated, very stiff.

BROWN SILTY SAND (SM) dense, saturated; with some gravel (Till).

Becomes moist.

Becomes gray.

With a trace of gravel.

GRAY GRAVELLY SILT (ML) very stiff, moist; with some sand.

DARK GRAY SILTSTONE, moderately consolidated, low hardness, weak, fresh.

AGI TECHNOLOGIES

Log of Well PZ-3 (0-40')

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

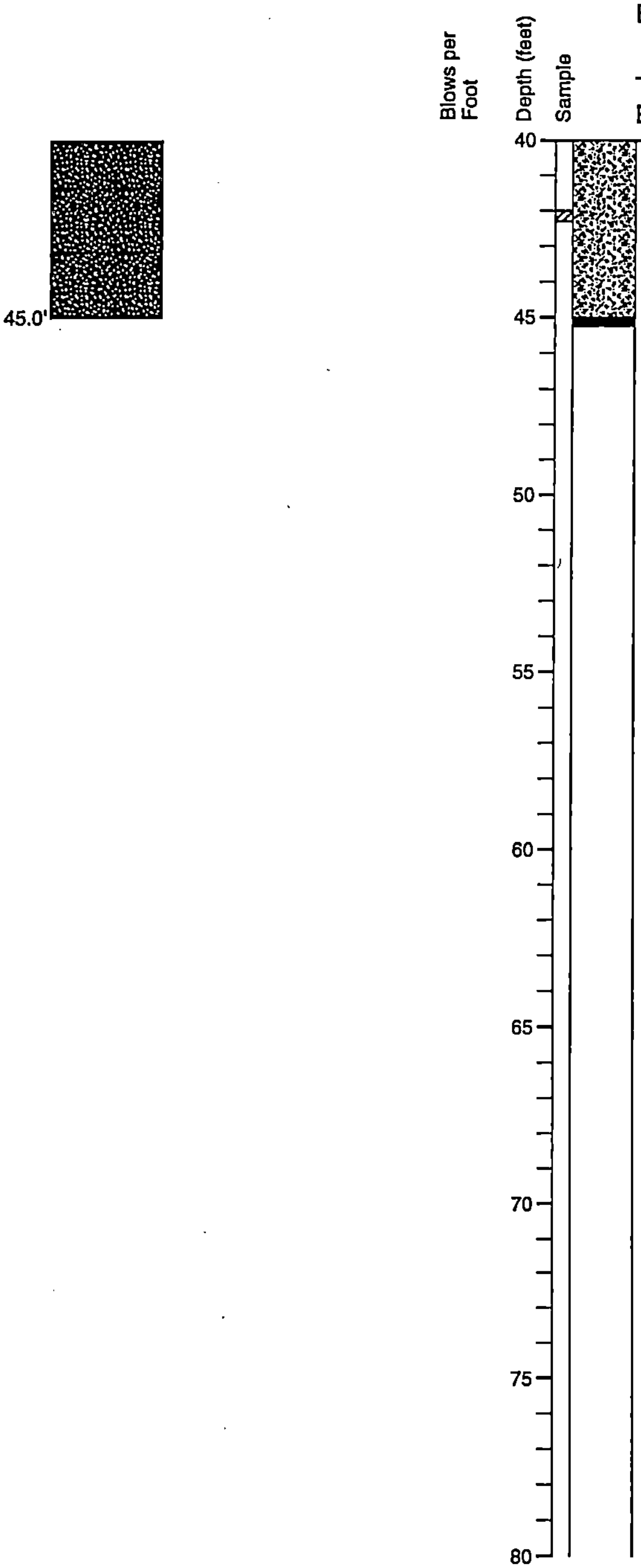
PLATE
C6a

	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
512108mw.cdr	15,512.108	JFL/ALW	4 April 95	TMM		

Equipment AP 1000 Dual Wall

Top of Casing Elevation 324.18 feet

Start Date 5/4/94



Platey with oriented mica flakes.

Boring terminated on 5/4/94
Groundwater encountered at 12 feet during drilling.

AGI TECHNOLOGIES

Log of Well PZ-3 (40-45')

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PLATE **C6b**

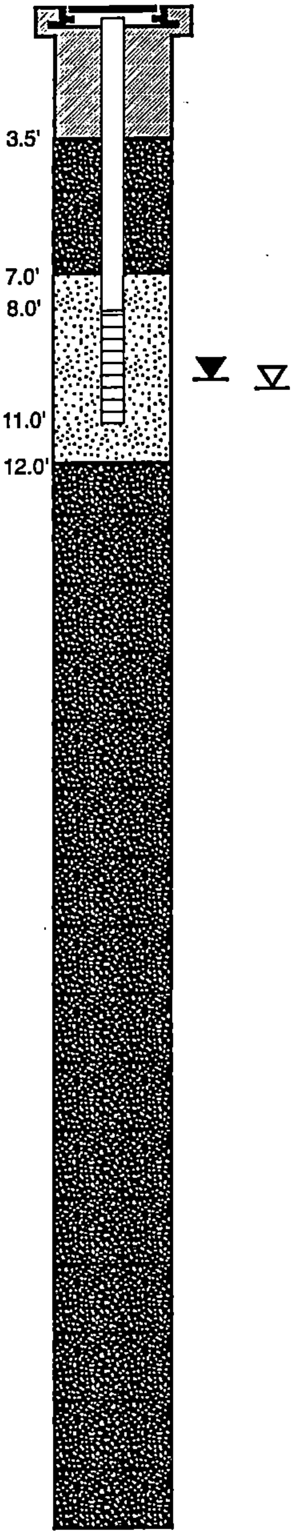
	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
512108mw.cdr	15,512.108	JFL/ALW	4 April 95	TMM		

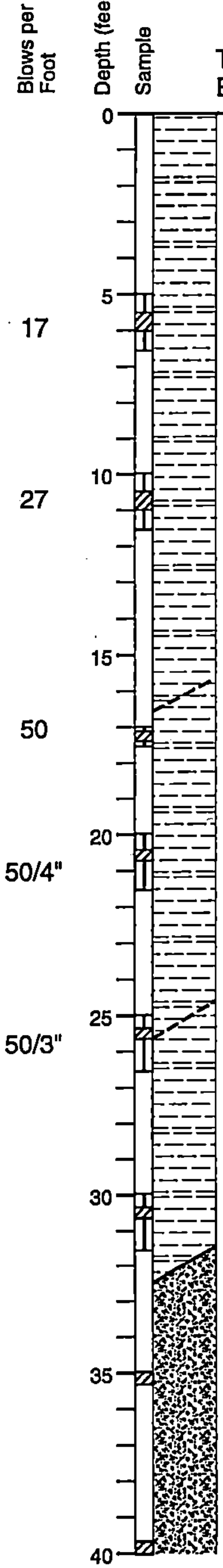
Equipment AP 1000 Dual Wall

Top of Casing Elevation 323.18 feet

Start Date 5/4/94

Well Construction Summary





BROWN SANDY SILT (ML) stiff, moist; with some gravel (Fill).

Becomes very stiff, wet (Till).

With a trace of wood fragments.
Becomes gray, very hard.

GRAY SANDY SILT (ML) very hard, moist; with a trace of gravel..

DARK GRAY SILT (ML) very hard, moist; with a trace of gravel (weathered siltstone).

With some bedrock fragments.
Bedrock encountered at approximately 32 feet.

DARK GRAY SILTSTONE, moderately consolidated, platey, low hardness, weak, fresh to little weathered, with thin micaceous laminations.

AGI TECHNOLOGIES

Log of Well PZ-4 (0-40')

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

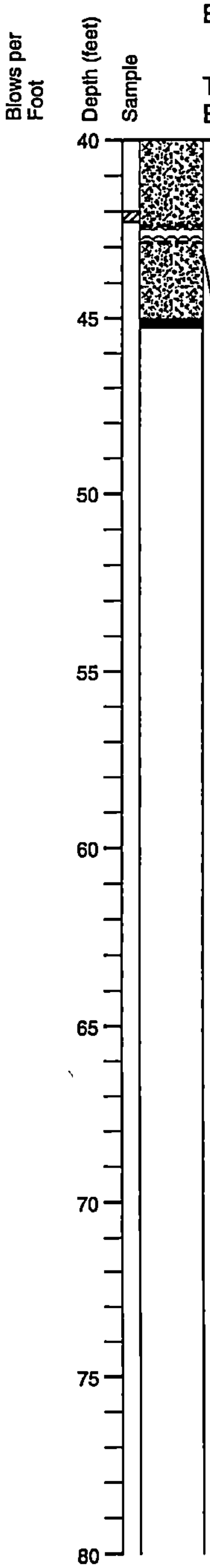
PLATE **C7a**

	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
512108mw.cdr	15,512.108	JFL/ALW	4 April 95	TMM		

Equipment AP 1000 Dual Wall

Top of Casing Elevation 323.18 feet

Start Date 5/4/94



DARK BROWN CLAY (OL) stiff, wet; with a trace of organics.

DARK GRAY SILTSTONE, moderately consolidated, platey, low hardness, weak, fresh to little weathered, with thin micaceous laminations.

Boring terminated on 5/4/94.

Groundwater encountered at 10 feet during drilling.

AGI TECHNOLOGIES

Log of Well PZ-4 (40-45')

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PLATE **C7b**

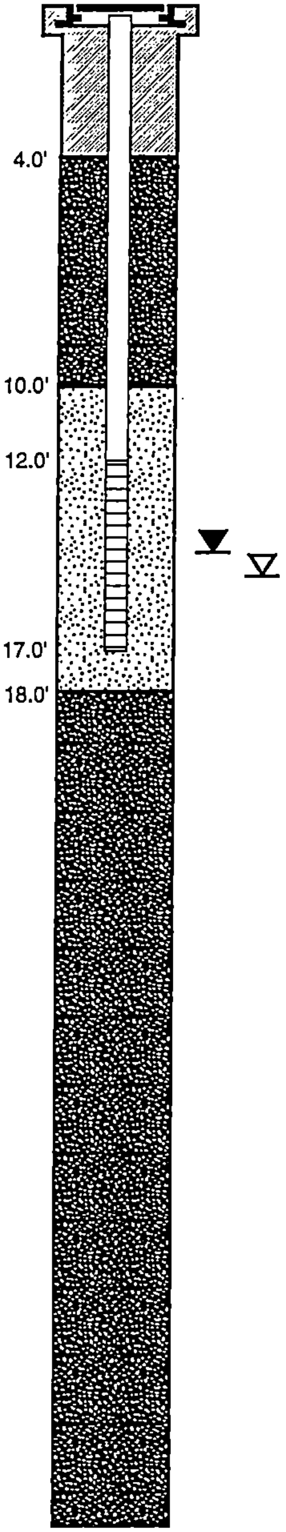
	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
512108mw.cdr	15,512.108	JFL/ALW	4 April 95	TMM		

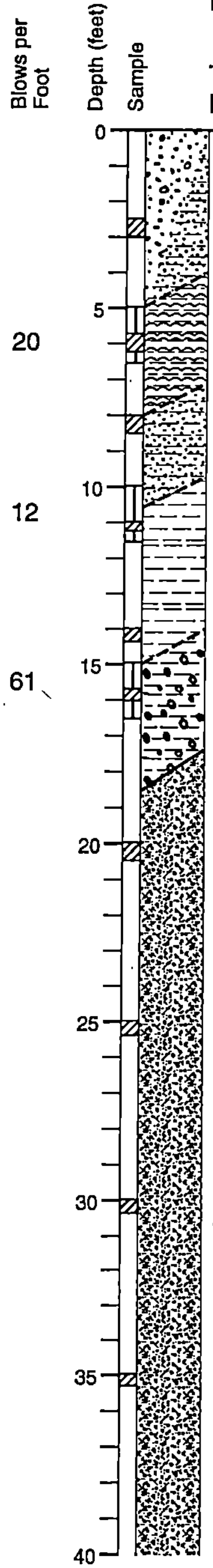
Equipment AP 1000 Dual Wall

Top of Casing Elevation 311.16 feet

Start Date 5/6/94

Well Construction Summary





GRAY SAND (SW-SM) moist; with some silt and gravel (Fill).

BROWN ORGANIC SILT (OL) very stiff, wet; with some fine sand and gravel and a trace of wood fragments (Fill).

GRAY SILTY SAND (SM) wet; with some gravel (Fill).

BROWN SANDY SILT (ML) stiff, saturated; with some gravel and a trace of wood fragments (Fill).

GRAY BROWN SILTY GRAVEL (GM) dense, saturated; with some sand (Alluvium).

Bedrock encountered at 18 feet.

DARK GRAY SILTSTONE, poorly consolidated, low hardness, friable to weakly strong, fresh.

Becomes moderately hard and moderately strong.

Becomes dry.

With thin seams of coal and mica.

AGI TECHNOLOGIES

Log of Well PZ-5 (0-40')

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

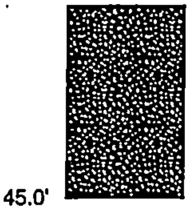
PLATE **C8a**

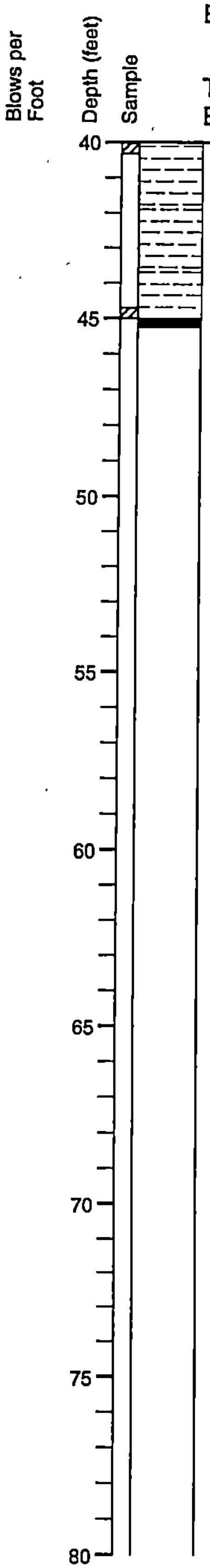
	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
512108mw.cdr	15,512.108	JFL/ALW	4 April 95	TMM		

Equipment AP 1000 Dual Wall

Top of Casing Elevation 311.16 feet

Start Date 5/6/94





Becomes shaley.

Boring terminated on 5/6/94.
Groundwater encountered at 15 feet during drilling.

AGI TECHNOLOGIES

Log of Well PZ-5 (40-45')

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

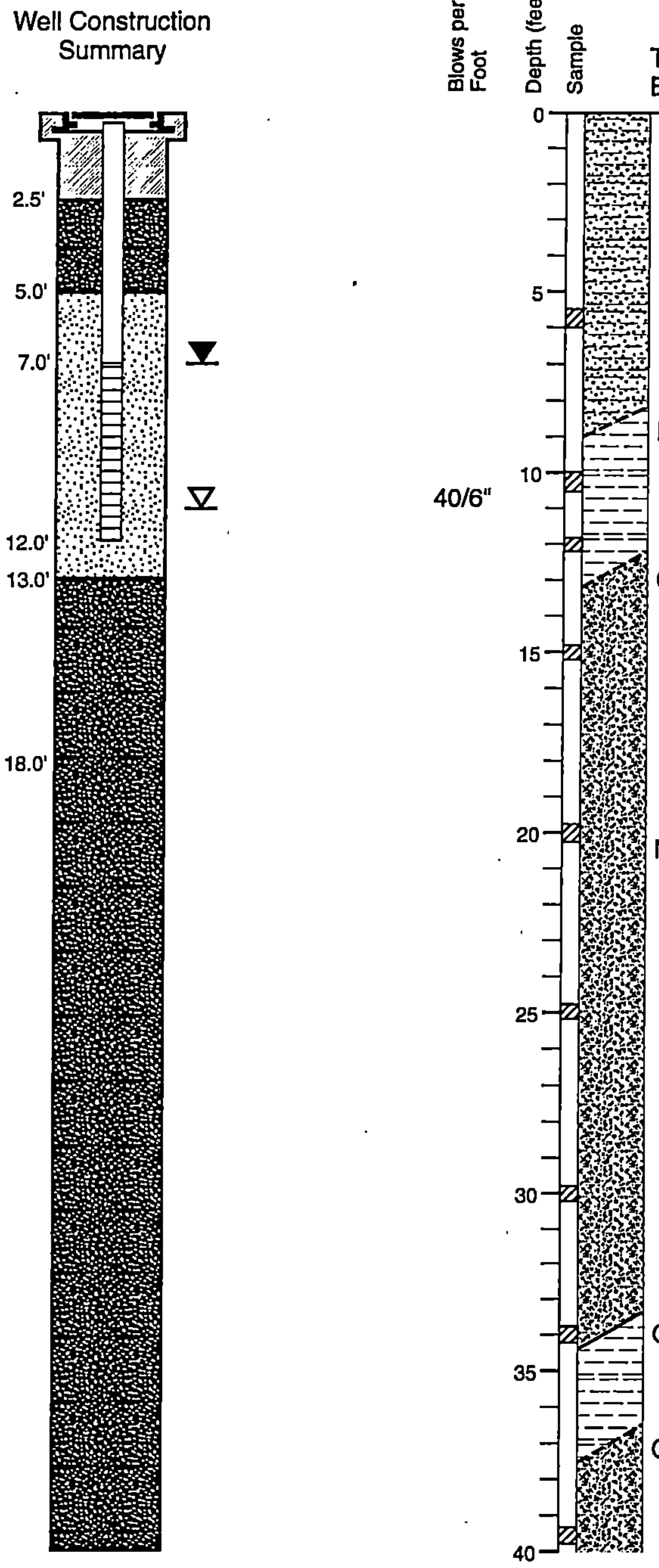
PLATE **C8b**

	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
512108mw.cdr	15,512.108	JFL/ALW	4 April 95	TMM		

Equipment AP 1000 Dual Wall

Top of Casing Elevation 311.96 feet

Start Date 5/3/94



BROWN SILTY SAND (SM) very dense, moist; with some gravel and a trace of organics (Fill).

BROWN SANDY SILT (ML) hard, wet; mottled, with some gravel.

GRAY SILTSTONE, moist, moderately consolidated, flaggy, low hardness, friable to weak, little weathering.

Moisture content increases.

GRAY BROWN SANDY SILT (ML) medium stiff, wet.

GRAY SANDY SILTSTONE, moist, well consolidated, flaggy, moderately hard, strong, fresh.

AGI TECHNOLOGIES

Log of Well PZ-6 (0-40')

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

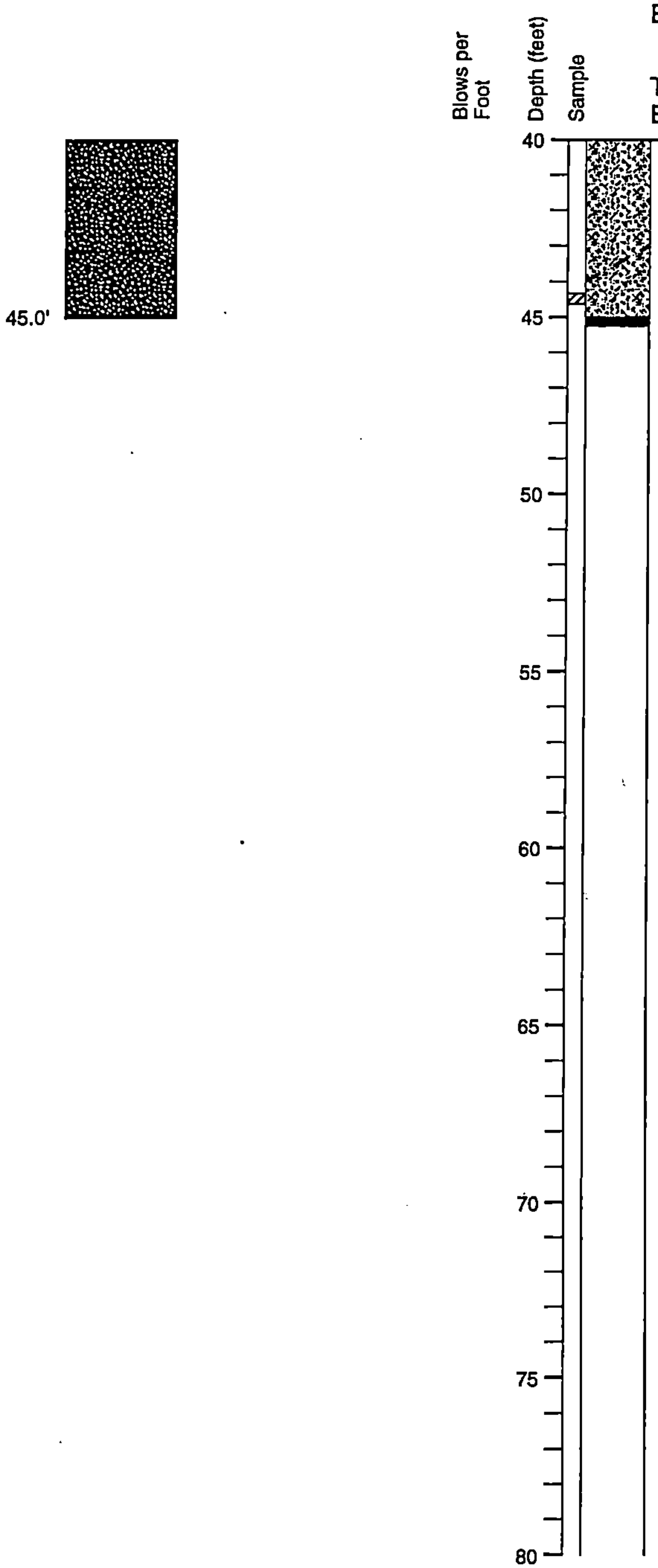
PLATE **C9a**

	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
512108mw.cdr	15,512.108	JFL/ALW	4 April 95	TUU		

Equipment AP 1000 Dual Wall

Top of Casing Elevation 311.96 feet

Start Date 5/3/94



DARK GRAY SILTSTONE, poorly to well consolidated, shaley, low hardness, weak, fresh.

Boring terminated on 5/3/94.

Groundwater encountered at 11 feet during drilling.

AGI TECHNOLOGIES

Log of Well PZ-6 (40-45')

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

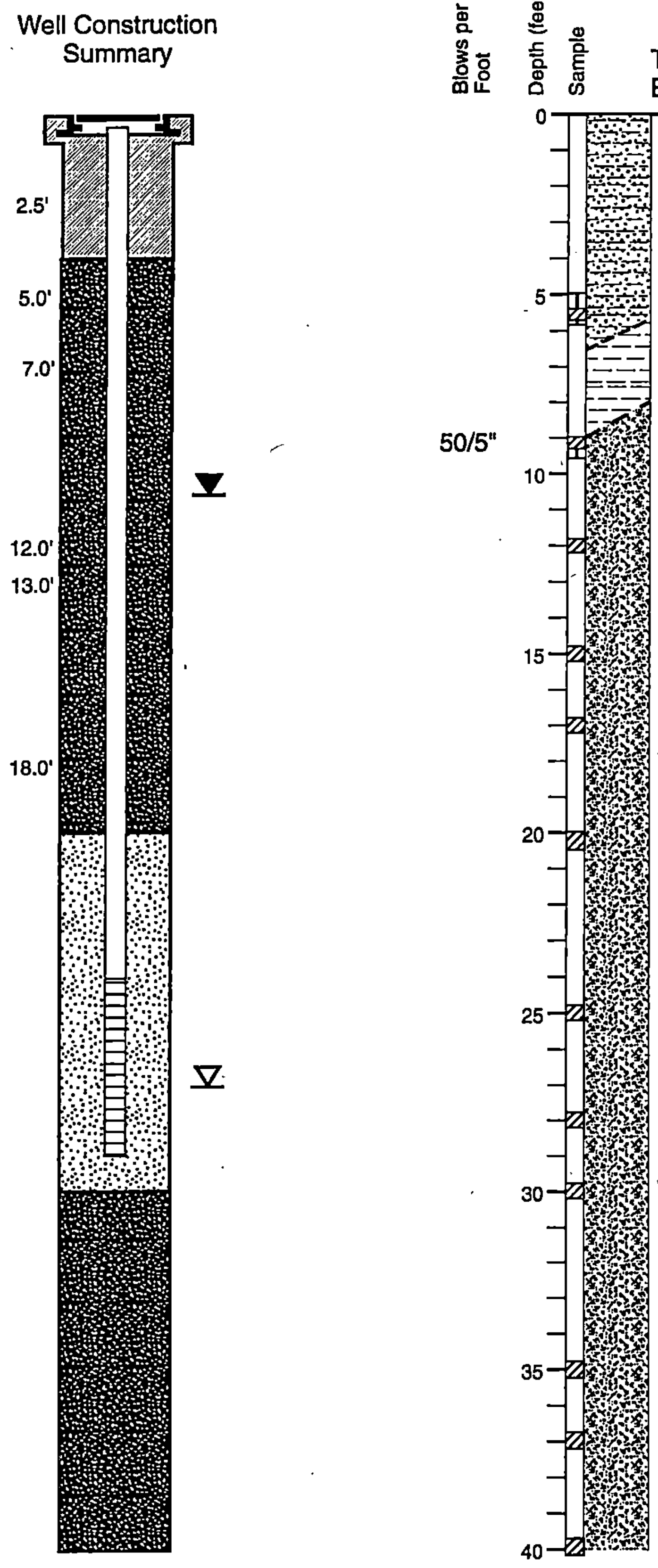
PLATE **C9b**

	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
512108mw.cdr	15,512.108	JFL/ALW	4 April 95	TMM		

Equipment AP 1000 Dual Wall

Top of Casing Elevation 311.16 feet

Start Date 5/2/94



GRAY BROWN SILTY SAND (SM) dense, moist; with some gravel (road base).

DARK BROWN SANDY SILT (ML) very hard, moist; with some gravel, gravel is siltstone.

GRAY SILTSTONE, well consolidated, flaggy, moderately hard, weak, fresh.

Becomes moist, with some fine to coarse sand, and a trace of shell fragments.

Without shell fragments.

Becomes strong.

Becomes moderately strong.

With some friable zones and micaceous seams.

Becomes weak.

AGI
TECHNOLOGIES

Log of Well PZ-7 (0-40')

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

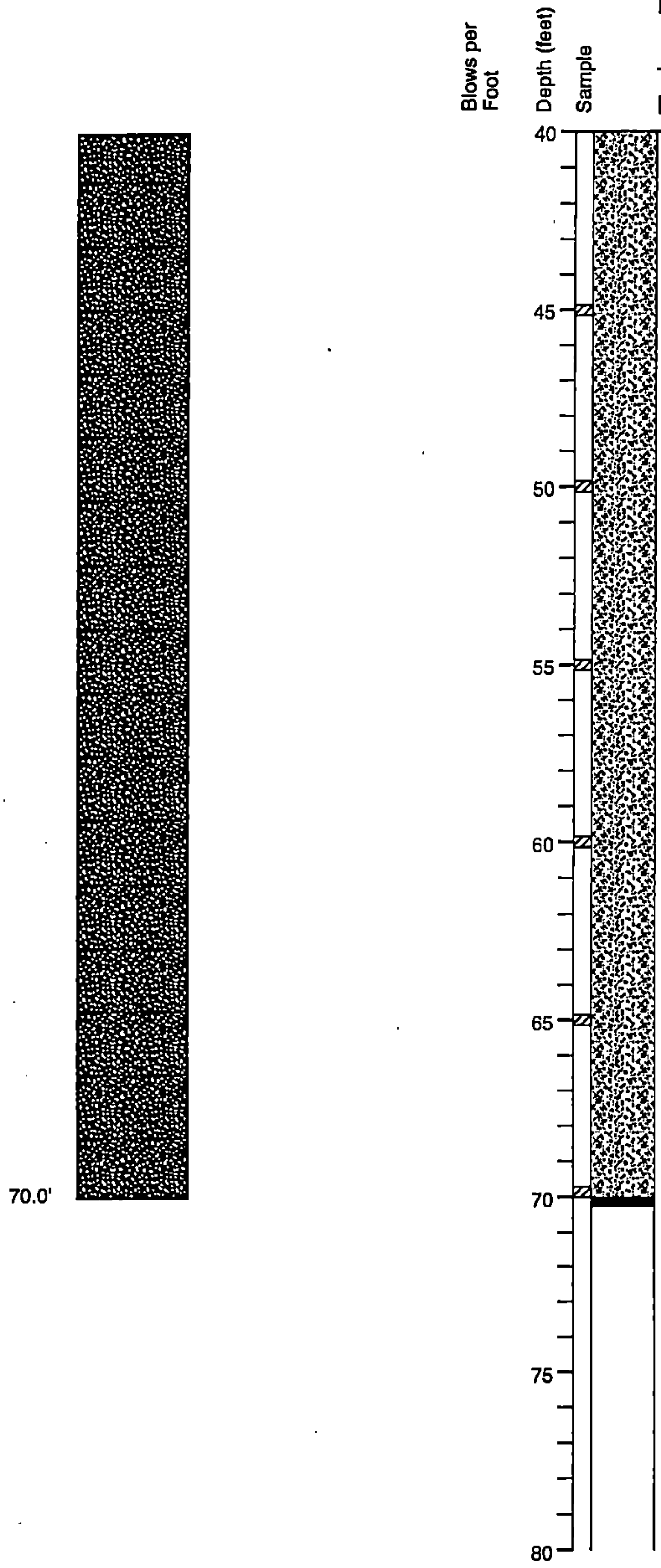
PLATE
C10a

	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
512108mw.cdr	15,512.108	JFL/ALW	4 April 95	TMM		

Equipment AP 1000 Dual Wall

Top of Casing Elevation 311.16 feet

Start Date 5/2/94



With some sand.

Boring terminated on 5/3/94.
Groundwater encountered at 27 feet during drilling.

Log of Well PZ-7 (40-70')

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

AGI TECHNOLOGIES

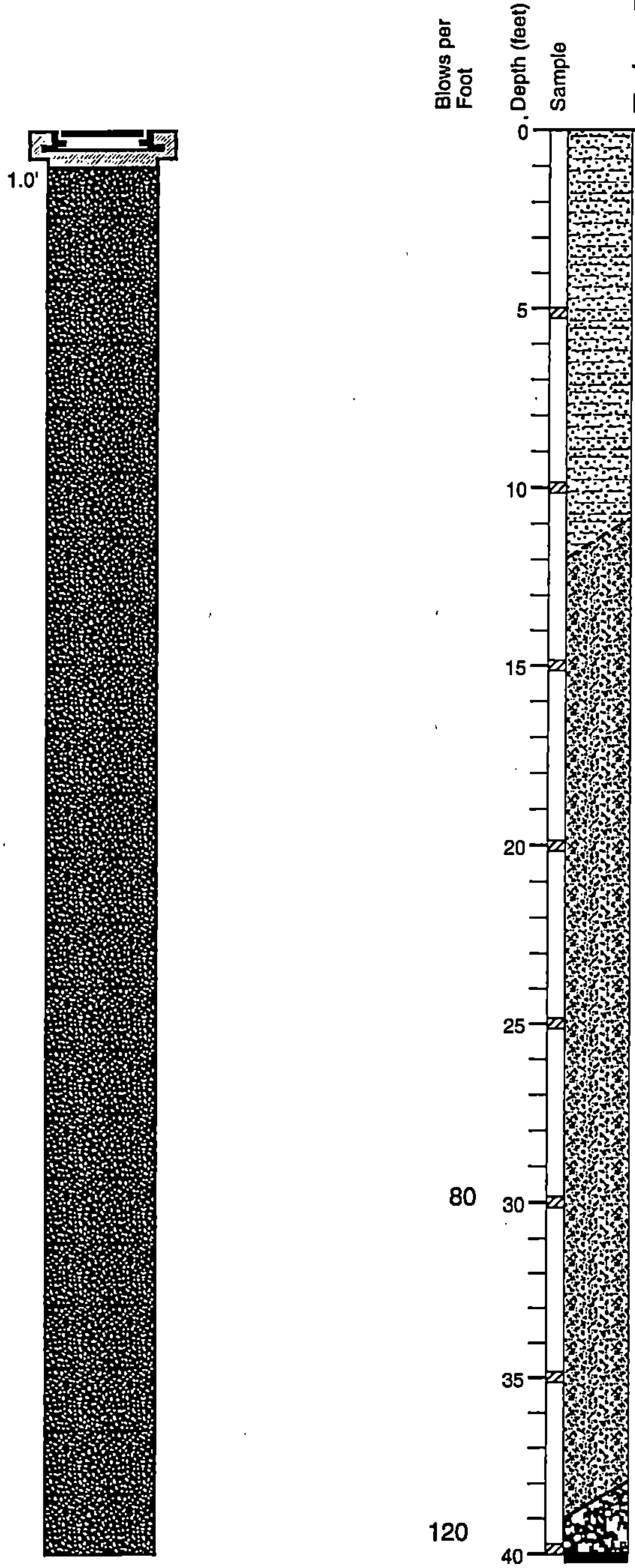
PLATE C10b

	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
512108mw.cdr	15,512.108	JFL/ALW	4 April 95	TMM		

Equipment AP 1000 Dual Wall

Top of Casing Elevation Abandoned

Start Date 5/3/94



GRAY BROWN SILTY SAND (SM) dense, moist; with some gravel (Fill).

DARK GRAY SILTSTONE, moderately consolidated, flaggy, low hardness, weak, fresh.

Becomes well consolidated.

With shell fragments.

Bedding becomes shaley, with fine dark gray micaceous laminations.

Occasional shells, petrified wood.

GRAY PEBBLE SANDSTONE CONGLOMERATE, moderately consolidated, flaggy, medium hard, weak, fresh.

Boring terminated on 5/3/94.

Groundwater not encountered during drilling.

AGI TECHNOLOGIES

Log of Boring G-24 (Abandoned)

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PLATE **C11**

	PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
512108m2.cdr	15,512.108	/JFL/ALW	4 April 95			

APPENDIX D

Cap Runoff Chemistry Evaluation and Surface Water Chemistry

APPENDIX D

Cap Runoff Chemistry Evaluation and Surface Water Chemistry

CAP RUNOFF CHEMISTRY

Cap runoff samples taken at location L-1 on December 2, 1993 indicated a specific conductivity of 850 micromhos per centimeter (µmhos/cm), a hardness of 400 milligrams per liter (mg/L), and sulfate of 270 mg/L. Other anionic and cationic species were not detected at concentrations that would be expected to affect the specific conductivity. Two different calculation methods were used to determine whether the sources of the high specific conductivity were sulfate and hardness.

The first method is an empirical relationship between total dissolved solids (TDS) and specific conductivity (SC). This approximate relationship is TDS = 0.64 SC, where TDS is in units of mg/L and SC is in units of µmhos/cm (G. Tchobanoglous and F. L. Burton, Wastewater Engineering: Treatment, Disposal, and Reuse, 1991, McGraw-Hill, New York, p. 1145). Assuming that hardness and sulfate represent the majority of the TDS, the calculated SC is 1,000 µmhos/cm, which is the same order of magnitude as the reported value of 850 µmhos/cm.

The second method calculates the specific conductivities associated with hardness and sulfate. The specific molar conductivity of sodium bicarbonate ($NaHCO_3$) was used to represent hardness and the specific molar conductivity of magnesium sulfate heptahydrate ($MgSO_4 \cdot 7H_2O$) was used to represent sulfate (R. C. Weast, Handbook of Chemistry and Physics, 56th Edition, 1975, CRC Press, Cleveland, p. D218 - D267). These selections were made based on geochemistry and data availability. The specific conductance of a solution of magnesium sulfate heptahydrate with 270 mg/L sulfate was calculated to be 570 µmhos/cm. The specific conductivity of a solution of sodium bicarbonate with a hardness (measured as calcium carbonate) of 400 mg/L was calculated to be 280 mg/L. These data add to a total of 850 µmhos/cm, which compares well to the observed value for the surface water. Selection of different indicator chemicals for sulfate and hardness would have given different numbers, but the result would be the same order of magnitude.

These results show that the specific conductivity associated with the Cathcart Landfill surface water is attributable to sulfate and hardness. The data also show that even though the concentration of hardness is greater than that of sulfate, the sulfate is the major source of the high specific conductivity.

SURFACE WATER CHEMISTRY

Surface water chemistry plots are provided in the following **Plates D-1 through D-20**. Surface water chemistry results for the fourth quarter 1994 round are presented in **Tables D-1 through D-3**.

Table D–1
General Parameters – Surface Water
Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Parameter	Detection Limit	Date Sampled	Sample I.D.								
			A	A–1	B	B–1	D	D–1	F	J	North Pond
pH		11/94	6.9	6.7	6.9	NA	NA	6.8	6.8	6.7	NA
		11/17/94	NA	NA	NA	NA	NA	7.3	NA	NA	NA
		12/02/94	6.2	6.2	NA	6.2	6.5	NA	6.2	7.2	6.8
		12/09/94	NA	NA	NA	NA	6.9	NA	6.7	NA	NA
Total Organic Cargon (mg/L)	1.0	11/94	7.5	4.8	5.5	NA	NA	45	8.2	7.5	NA
	1.0	11/17/94	NA	NA	NA	NA	NA	10	NA	NA	NA
	1.0	12/02/94	3.6	3.1	NA	7.5	8.0	NA	3.5	3.5	8.8
	1.0	12/09/94	NA	NA	NA	NA	11	NA	3.8	NA	NA
Chemical Oxygen Demand (mg/L)	10	11/94	NA	NA	NA	NA	NA	NA	NA	NA	NA
	10	11/17/94	NA	NA	NA	NA	NA	NA	NA	NA	NA
	10	12/02/94	NA	NA	NA	NA	NA	NA	NA	NA	NA
	10	12/09/94	NA	NA	NA	NA	NA	NA	NA	NA	NA
Biochemical Oxygen Demand (mg/L)	10	11/94	ND	ND	ND	NA	NA	ND	ND	ND	NA
	10	11/17/94	NA	NA	NA	NA	NA	ND	NA	NA	NA
	10	12/02/94	ND	ND	NA	ND	ND	NA	ND	ND	ND
	10	12/09/94	NA	NA	NA	NA	ND	NA	ND	NA	NA
Chloride (mg/L)	1.0	11/94	7.8	3.5	2.5	NA	NA	48	5.2	5.4	NA
	1.0	11/17/94	NA	NA	NA	NA	NA	6.7	NA	NA	NA
	1.0	12/02/94	6.5	8.3	NA	5.7	4.9	NA	6.0	6.0	4.5
	1.0	12/09/94	NA	NA	NA	NA	4.5	NA	6.5	NA	NA
Conductivity (µmhos/cm)	0.5	11/94	140	200	440	NA	NA	1,500	580	540	NA
	0.5	11/17/94	NA	NA	NA	NA	NA	710	NA	NA	NA
	0.5	12/02/94	170	160	NA	140	640	NA	200	150	650
	0.5	12/09/94	NA	NA	NA	NA	630	NA	170	NA	NA
Hardness (mg/L)	1.0	11/94	44	73	170	NA	NA	580	250	240	NA
	1.0	11/17/94	NA	NA	NA	NA	NA	340	NA	NA	NA
	1.0	12/02/94	51	37	NA	36	260	NA	57	65	270
	1.0	12/09/94	NA	NA	NA	NA	230	NA	45	NA	NA
Ammonia Nitrogen (mg/L)	0.005	11/94	0.007	0.24	0.029	NA	NA	0.15	0.018	0.085	NA
	0.005	11/17/94	NA	NA	NA	NA	NA	0.016	NA	NA	NA
	0.005	12/02/94	0.010	0.013	NA	0.012	0.011	NA	ND	ND	0.029
	0.005	12/09/94	NA	NA	NA	NA	0.14	NA	ND	NA	NA

Table D–1
General Parameters – Surface Water
Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Parameter	Detection Limit	Date Sampled	Sample I.D.								
			A	A–1	B	B–1	D	D–1	F	J	North Pond
Nitrate + Nitrite Nitrogen (mg/L)	0.01	11/94	2.0	0.35	0.53	NA	NA	1.3	0.85	1.3	NA
	0.01	11/17/94	NA	NA	NA	NA	NA	2.6	NA	NA	NA
	0.01	12/02/94	3.7	4.2	NA	5.4	1.5	NA	3.8	3.6	1.6
	0.01	12/09/94	NA	NA	NA	NA	1.7	NA	3.9	NA	NA
Nitrite Nitrogen (mg/L)	0.001	11/94	0.004	0.025	0.009	NA	NA	0.011	0.002	0.002	NA
	0.001	11/17/94	NA	NA	NA	NA	NA	0.011	NA	NA	NA
	0.001	12/02/94	0.004	0.003	NA	0.002	0.004	NA	0.004	0.004	0.009
	0.001	12/09/94	NA	NA	NA	NA	0.001	NA	0.001	NA	NA
Sulfate (mg/L)	10	11/94	25	49	74	NA	NA	300	200	200	NA
	10	11/17/94	NA	NA	NA	NA	NA	24	NA	NA	NA
	10	12/02/94	19	46	NA	5.2	200	NA	17	47	230
	10	12/09/94	NA	NA	NA	NA	200	NA	34	NA	NA
Total Coliforms (cfu/100 ml)	1	11/94	450	73	63	NA	NA	ND	60	75	NA
	1	11/17/94	NA	NA	NA	NA	NA	1	NA	NA	NA
	1	12/02/94	75	41	NA	20	1	NA	26	24	ND
	1	12/09/94	NA	NA	NA	NA	1	NA	6	NA	NA
Turbidity (NTU)	10	11/94	4.4	3.8	9.3	NA	NA	26	1.4	1.2	NA
	10	11/17/94	NA	NA	NA	NA	NA	0.84	NA	NA	NA
	10	12/02/94	2.4	4.8	NA	0.60	2.2	NA	1.5	1.6	1.0
	10	12/09/94	NA	NA	NA	NA	0.50	NA	0.60	NA	NA

Notes:

NA – Not analyzed.
ND – Not detected.
mg/L – Milligrams per liter.
µmhos/cm – Micromhos per centimeter.

Table D–2
Total Metals – Surface Water
Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

	Detection		Sample I.D.								
Metal	Limit (mg/L)	Date Sampled	A	A–1	B	B–1	D	D–1	F	J	North Pond
Arsenic	0.001	11/94	ND	0.001	ND	NA	NA	0.002	ND	ND	NA
	0.001	11/17/94	NA	NA	NA	NA	NA	ND	NA	NA	NA
	0.001	12/02/94	ND	ND	NA	ND	0.001	NA	ND	ND	ND
	0.001	12/09/94	NA	NA	NA	NA	0.001	NA	0.001	NA	NA
Barium	0.003	11/94	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cadmium	0.002	11/94	ND	ND	0.007	NA	NA	ND	ND	ND	NA
	0.002	11/17/94	NA	NA	NA	NA	NA	ND	NA	NA	NA
	0.002	12/02/94	0.003	0.004	NA	0.002	0.002	NA	ND	ND	0.002
	0.002	12/09/94	NA	NA	NA	NA	ND	NA	ND	NA	NA
Chromium	0.006	11/94	ND	ND	ND	NA	NA	ND	ND	ND	NA
	0.006	11/17/94	NA	NA	NA	NA	NA	ND	NA	NA	NA
	0.006	12/02/94	ND	ND	NA	ND	ND	NA	ND	ND	ND
	0.006	12/09/94	NA	NA	NA	NA	ND	NA	ND	NA	NA
Copper	0.002	11/94	ND	0.003	0.005	NA	NA	ND	0.006	0.007	NA
	0.002	11/17/94	NA	NA	NA	NA	NA	0.009	NA	NA	NA
	0.002	12/02/94	ND	0.002	NA	0.006	0.008	NA	ND	ND	0.004
	0.002	12/09/94	NA	NA	NA	NA	0.002	NA	ND	NA	NA
Iron	0.01	11/94	0.27	0.42	0.50	NA	NA	2.5	0.09	0.12	NA
	0.01	11/17/94	NA	NA	NA	NA	NA	0.07	NA	NA	NA
	0.01	12/02/94	0.13	0.29	NA	0.06	0.18	NA	0.14	0.11	0.07
	0.01	12/09/94	NA	NA	NA	NA	0.06	NA	0.30	NA	NA
Mercury	0.0002	11/94	ND	ND	ND	NA	NA	0.0005	ND	ND	NA
	0.0002	11/17/94	NA	NA	NA	NA	NA	0.0008	NA	NA	NA
	0.0002	12/02/94	ND	0.0004	NA	ND	ND	NA	0.0005	ND	ND
	0.0002	12/09/94	NA	NA	NA	NA	ND	NA	0.0003	NA	NA
Manganese	0.002	11/94	NA	NA	NA	NA	NA	NA	NA	NA	NA
Nickel	0.01	11/94	ND	ND	0.01	NA	NA	0.02	ND	ND	NA
	0.01	11/17/94	NA	NA	NA	NA	NA	0.01	NA	NA	NA
	0.01	12/02/94	ND	ND	NA	ND	ND	NA	ND	ND	ND
	0.01	12/09/94	NA	NA	NA	NA	0.01	NA	ND	NA	NA

Table D–2
Total Metals – Surface Water

Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

			Sample I.D.								
Metal	Detection Limit (mg/L)	Date Sampled	A	A–1	B	B–1	D	D–1	F	J	North Pond
Lead	0.001	11/94	0.001	0.001	ND	NA	NA	0.001	ND	0.001	NA
	0.001	11/17/94	NA	NA	NA	NA	NA	ND	NA	NA	NA
	0.001	12/02/94	0.001	0.001	NA	ND	ND	NA	ND	0.010	0.010
	0.001	12/09/94	NA	NA	NA	NA	0.003	NA	0.002	NA	NA
Selenium	0.001	11/94	NA	NA	NA	NA	NA	NA	NA	NA	NA
Silver	0.01	11/94	ND	ND	ND	NA	NA	ND	ND	ND	NA
	0.01	11/17/94	NA	NA	NA	NA	NA	ND	NA	NA	NA
	0.01	12/02/94	ND	ND	NA	ND	ND	NA	ND	ND	ND
	0.01	12/09/94	NA	NA	NA	NA	ND	NA	ND	NA	NA
Zinc	0.002	11/94	0.010	0.020	0.081	NA	NA	0.11	0.066	0.042	NA
	0.002	11/17/94	NA	NA	NA	NA	NA	0.016	NA	NA	NA
	0.002	12/02/94	0.014	0.019	NA	0.009	0.014	NA	0.030	0.024	0.018
	0.002	12/09/94	NA	NA	NA	NA	0.023	NA	ND	NA	NA

Notes:

mg/L – Milligrams per liter.
NA – Not analyzed.
ND – Not detected.

Table D–3
Volatile Organic Compounds – Surface Water

Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

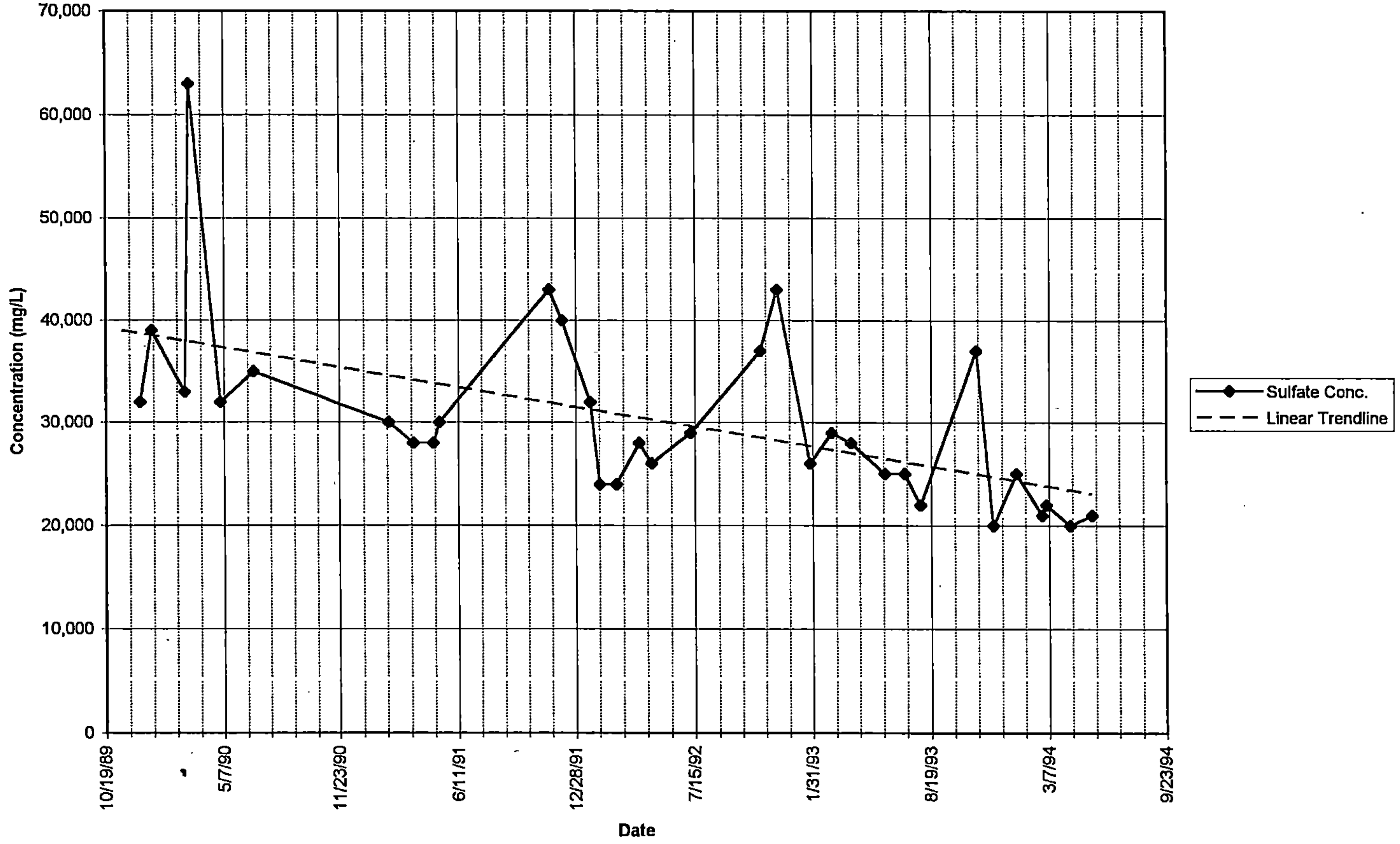
Compound	Detection Limit (µg/L)	Date Sampled	Sample I.D. W–1 µg/L
Chloromethane	5.0	11/94	ND
	5.0	12/94	NA
Vinyl Chloride	5.0	11/94	ND
	5.0	12/94	NA
Bromomethane	5.0	11/94	ND
	5.0	12/94	NA
Chloroethane	5.0	11/94	ND
	5.0	12/94	NA
Trichlorofluoromethane	1.0	11/94	ND
	1.0	12/94	NA
1,1–Dichloroethylene	1.0	11/94	ND
	1.0	12/94	NA
Acetone	20	11/94	ND
	20	12/94	NA
Carbon Disulfide	1.0	11/94	ND
	1.0	12/94	NA
Methylene Chloride	1.0	11/94	3.0 B
	1.0	12/94	NA
1,2–Dichloroethylene	1.0	11/94	ND
	1.0	12/94	NA
1,1–Dichloroethane	1.0	11/94	ND
	1.0	12/94	NA
Vinyl Acetate	10	11/94	ND
	10	12/94	NA
2–Butanone (MEK)	10	11/94	ND
	10	12/94	NA
Chloroform	1.0	11/94	ND
	1.0	12/94	NA
1,1,1–Trichloroethane	1.0	11/94	ND
	1.0	12/94	NA
Carbon Tetrachloride	1.0	11/94	ND
	1.0	12/94	NA
Benzene	1.0	11/94	ND
	1.0	12/94	NA
1,2–Dichloroethane	1.0	11/94	ND
	1.0	12/94	NA
1,1,2–Trichloroethene	1.0	11/94	ND
	1.0	12/94	NA
Bromodichloromethane	1.0	11/94	ND
	1.0	12/94	NA
1,2–Dichloropropane	1.0	11/94	ND
	1.0	12/94	NA
4–Methyl–2–Pentanone	10	11/94	ND
	10	12/94	NA

Table D–3
Volatile Organic Compounds – Surface Water
Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Compound	Detection Limit (µg/L)	Date Sampled	Sample I.D. W–1 µg/L
Toluene	1.0	11/94	1.2
	1.0	12/94	NA
cis–1,3–Dichloropropene	1.0	11/94	ND
	1.0	12/94	NA
1,1,2–Trichloroethane	1.0	11/94	ND
	1.0	12/94	NA
Tetrachloroethylene	1.0	11/94	ND
	1.0	12/94	NA
2–Hexanone	10	11/94	ND
	10	12/94	NA
Chlorodibromomethane	1.0	11/94	ND
	1.0	12/94	NA
Chlorobenzene	1.0	11/94	ND
	1.0	12/94	NA
Ethylbenzene	1.0	11/94	ND
	1.0	12/94	NA
Total Xylenes	1.0	11/94	1.2
	1.0	12/94	NA
Styrene	1.0	11/94	ND
	1.0	12/94	NA
Bromoform	1.0	11/94	ND
	1.0	12/94	NA
1,1,2,2–Tetrachloroethane	1.0	11/94	ND
	1.0	12/94	NA
trans–1,3–Dichloropropene	1.0	11/94	ND
	1.0	12/94	NA
p–Dichlorobenzene	1.0	11/94	ND
	1.0	12/94	NA

Notes:

NA – Not analyzed.
ND – Not detected.
µg/L – Micrograms per liter.



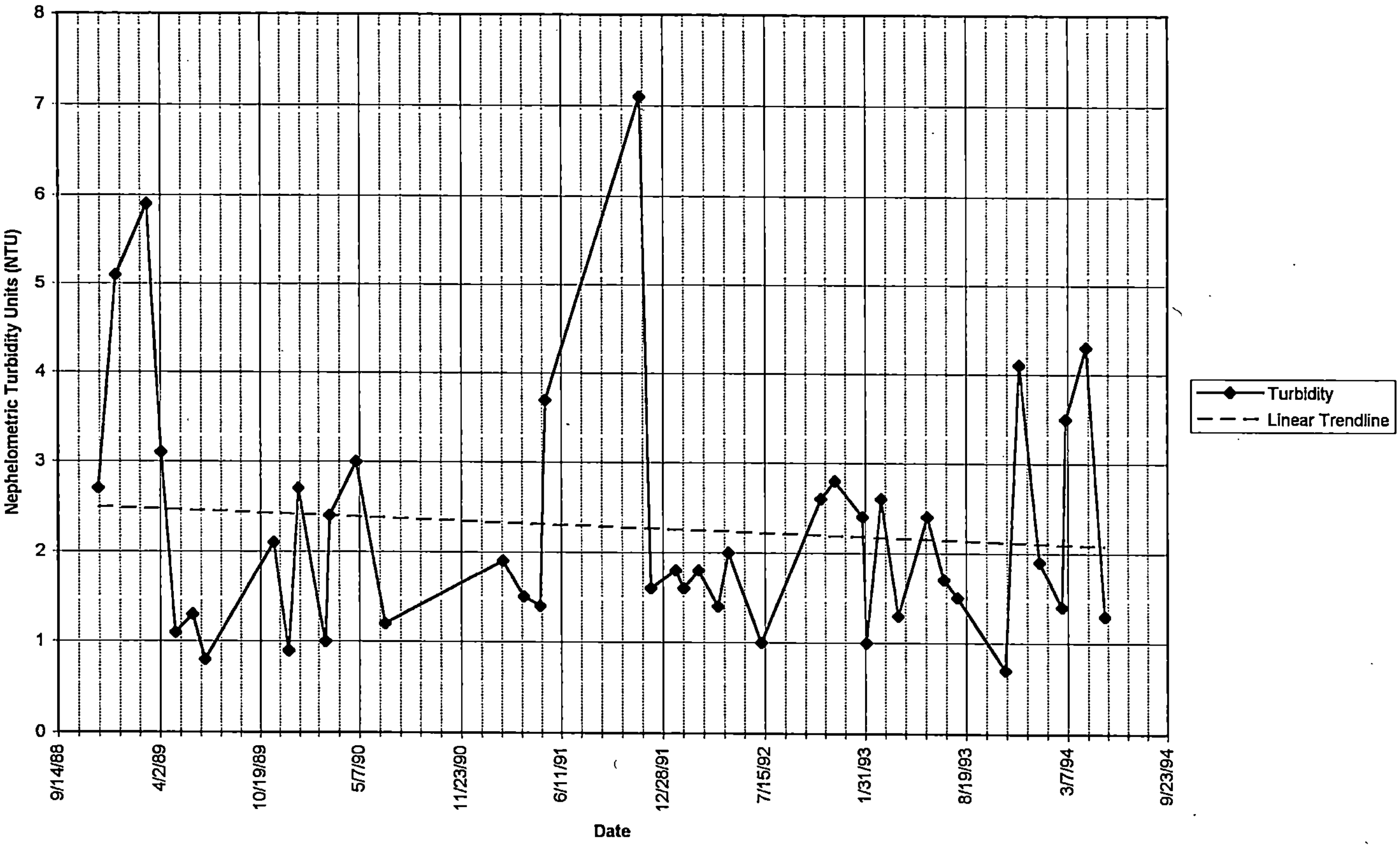
AGI
TECHNOLOGIES

Sulfate at Location A - Garden Creek

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	6 Mar 95	TMM		

PLATE
D1



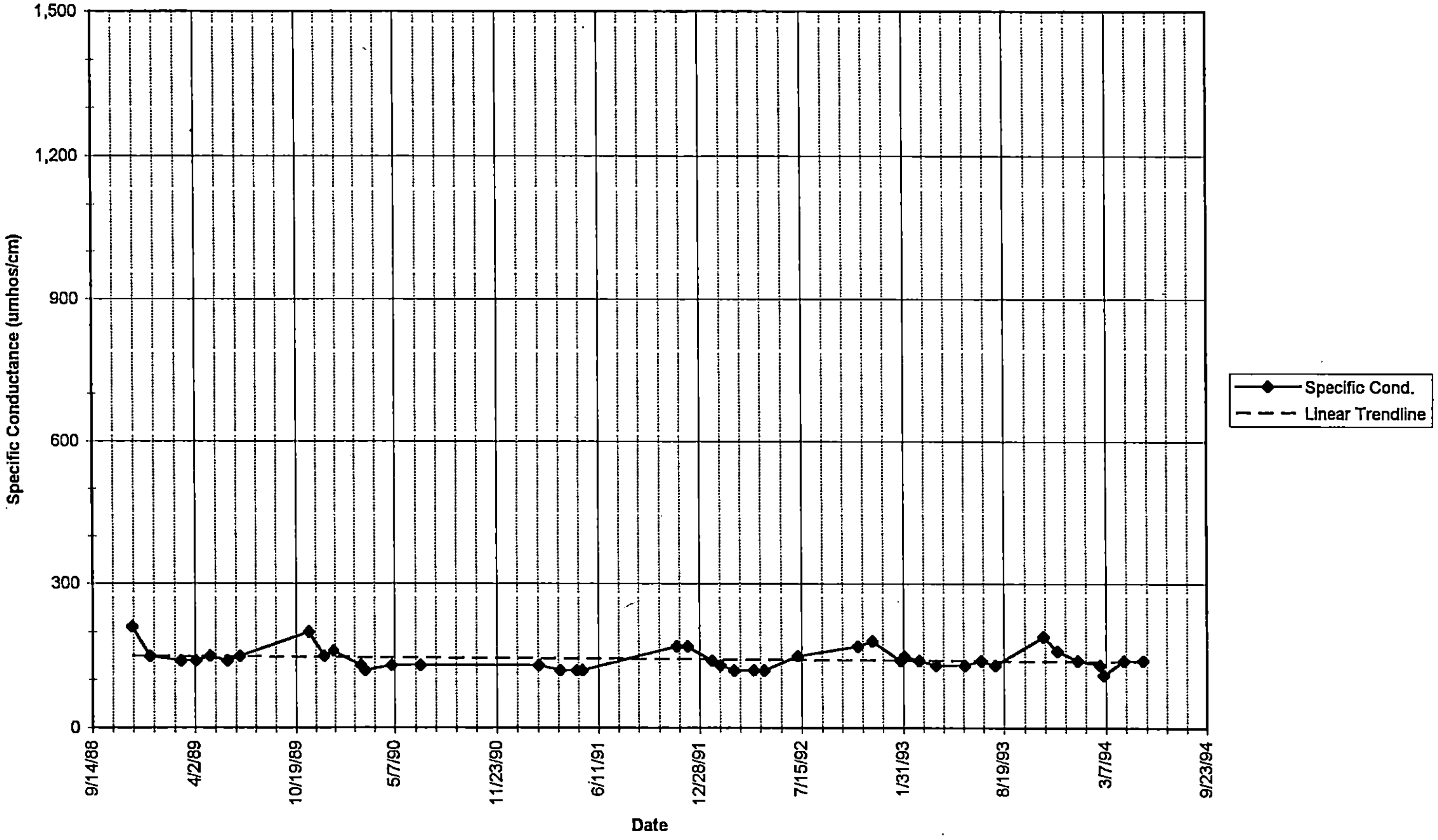
AGI
TECHNOLOGIES

Turbidity at Location A - Garden Creek

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	6 Mar 95	TMM		

PLATE:
D2



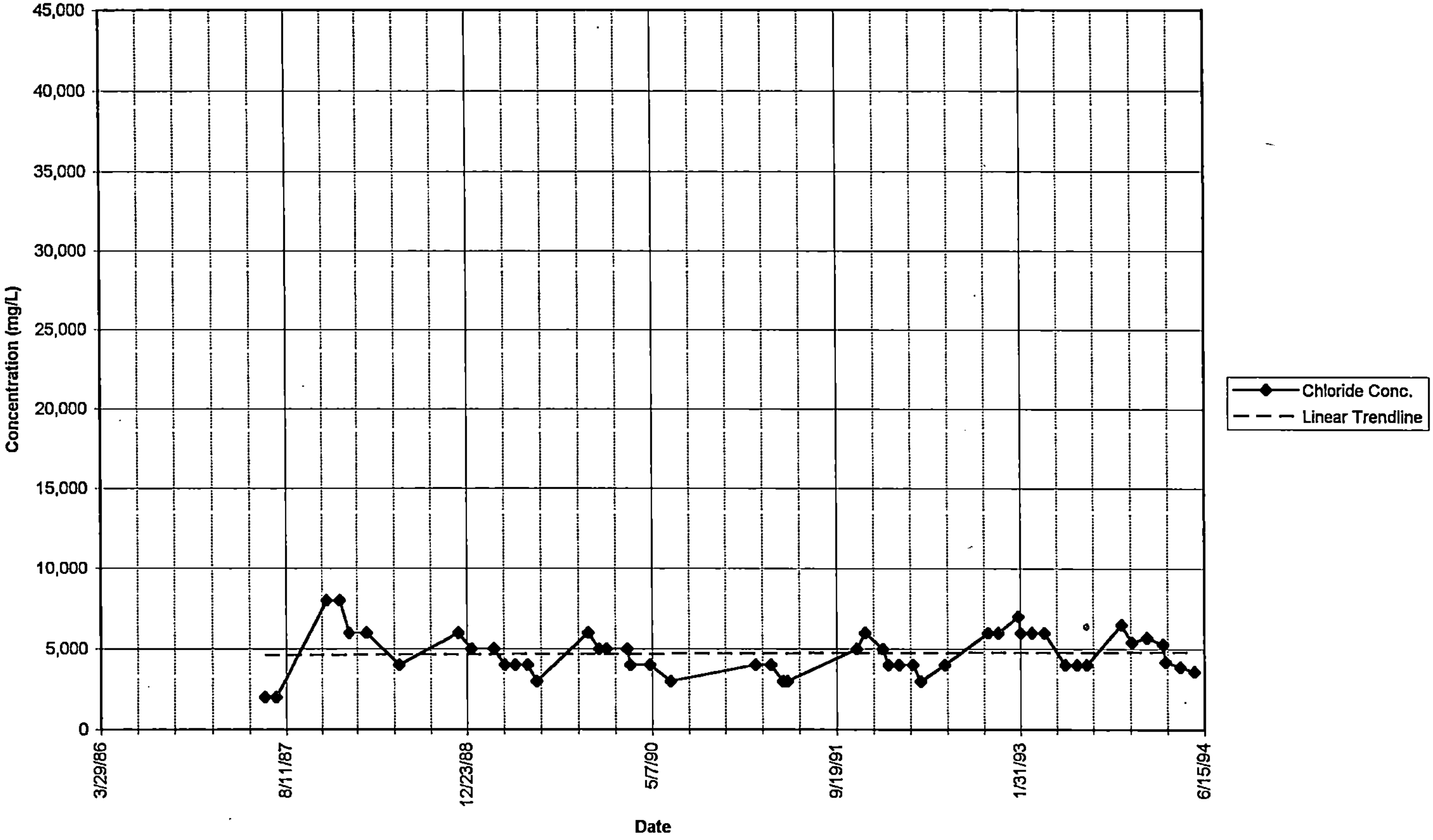
AGI
TECHNOLOGIES

Specific Conductance at Location A - Garden Creek

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	6 Mar 95	TMM		

PLATE:
D3



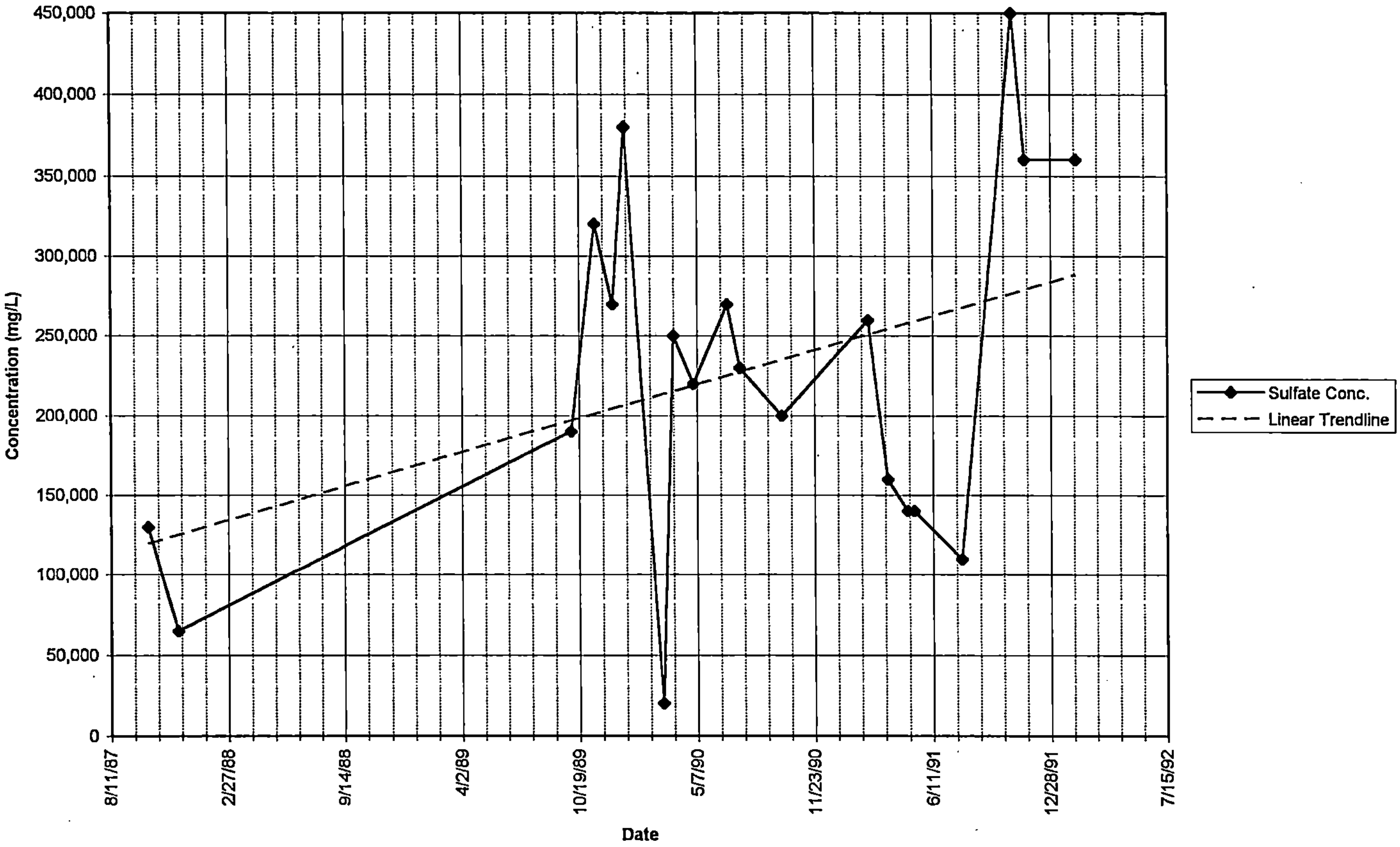
AGI
TECHNOLOGIES

Chloride Concentration at Location A - Garden Creek

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PLATE
D4

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	6 Mar 95	TMM		



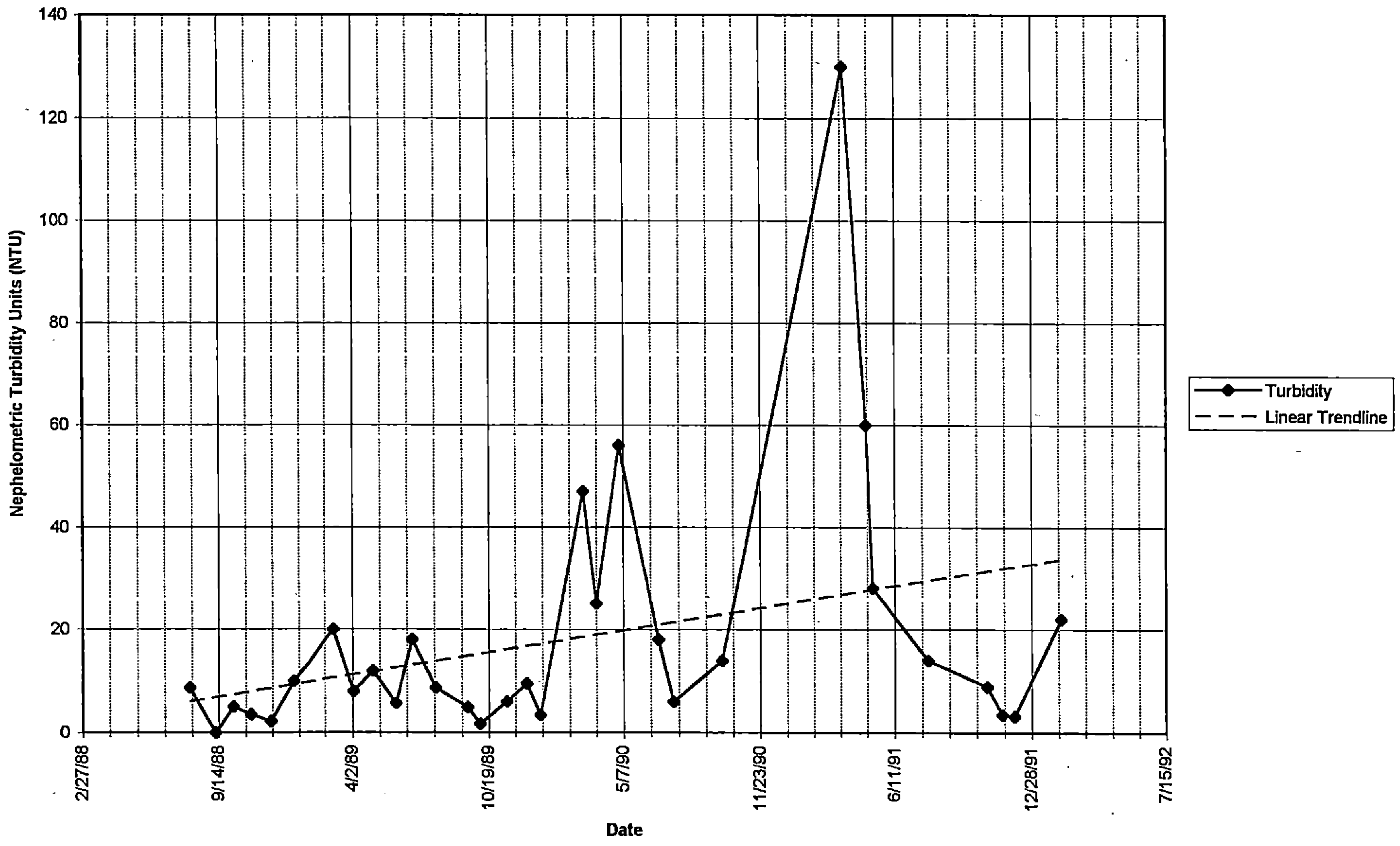
AGI
TECHNOLOGIES

Sulfate at Location C - Garden Creek

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PLATE
D5

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	6 Mar 95	TMM		



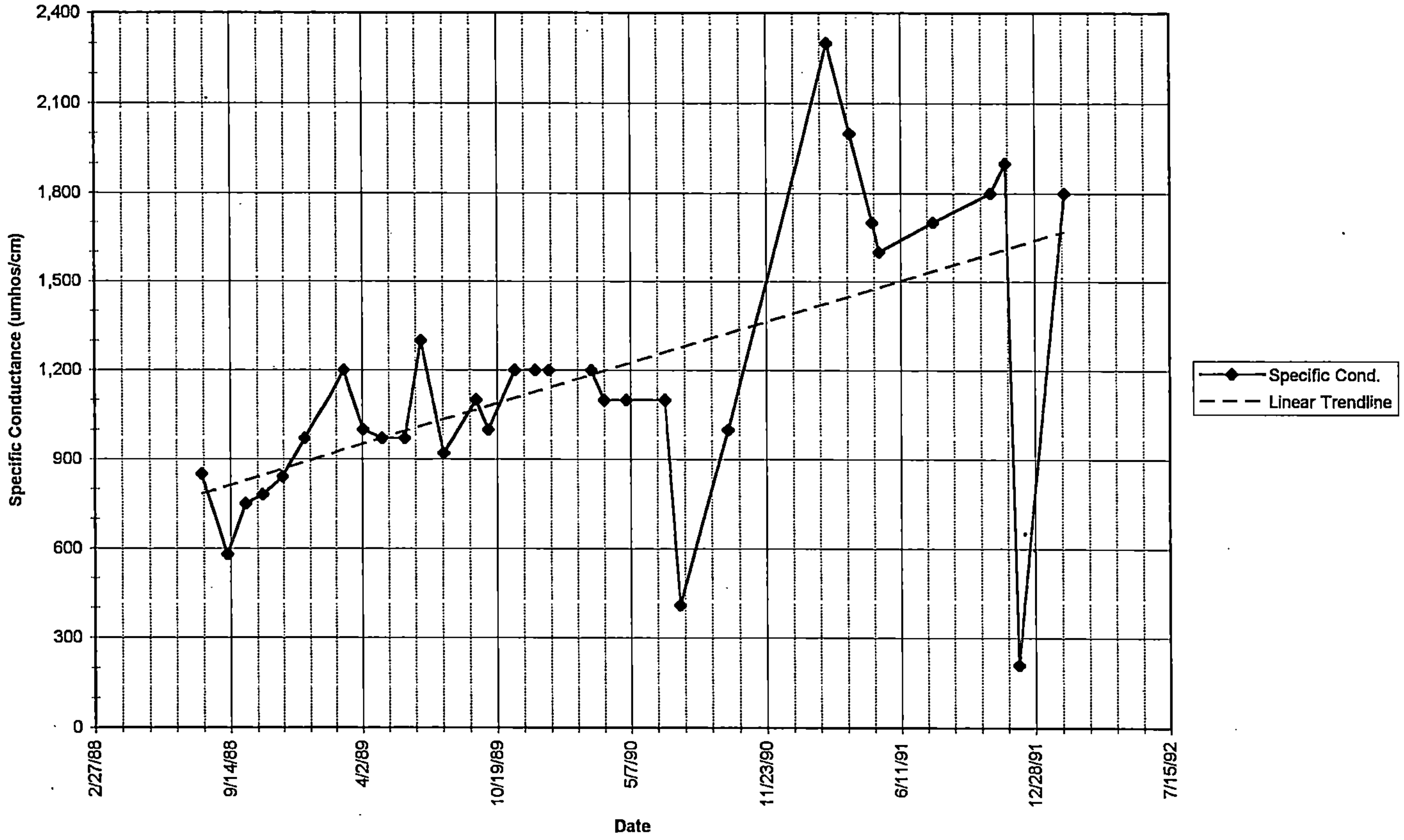
AGI
TECHNOLOGIES

Turbidity at Location C - Garden Creek

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	6 Mar 95	TMM		

PLATE
D6



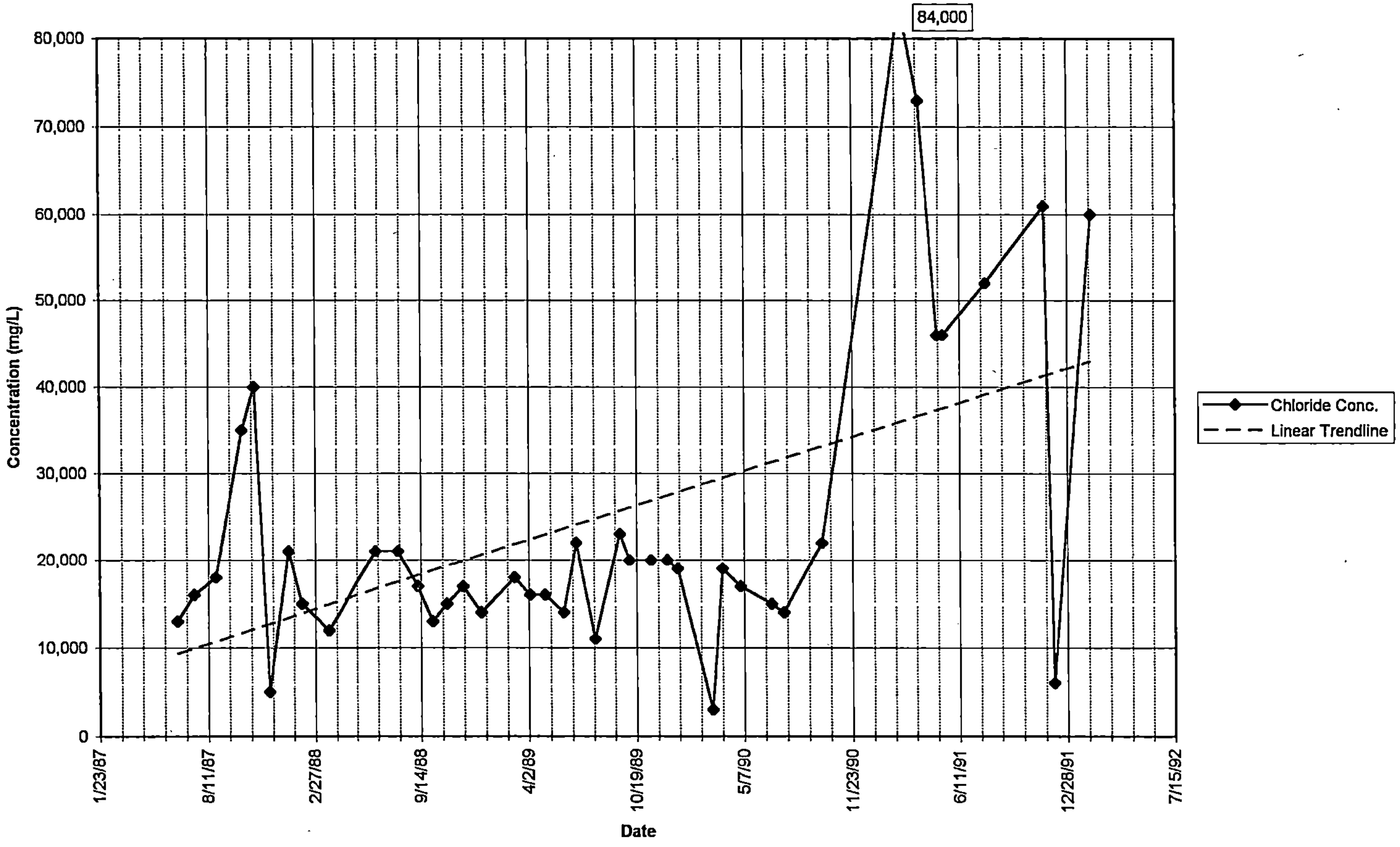
AGI
TECHNOLOGIES

Specific Conductance at Location C - Garden Creek

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	6 Mar 95	TMM		

PLATE
D7



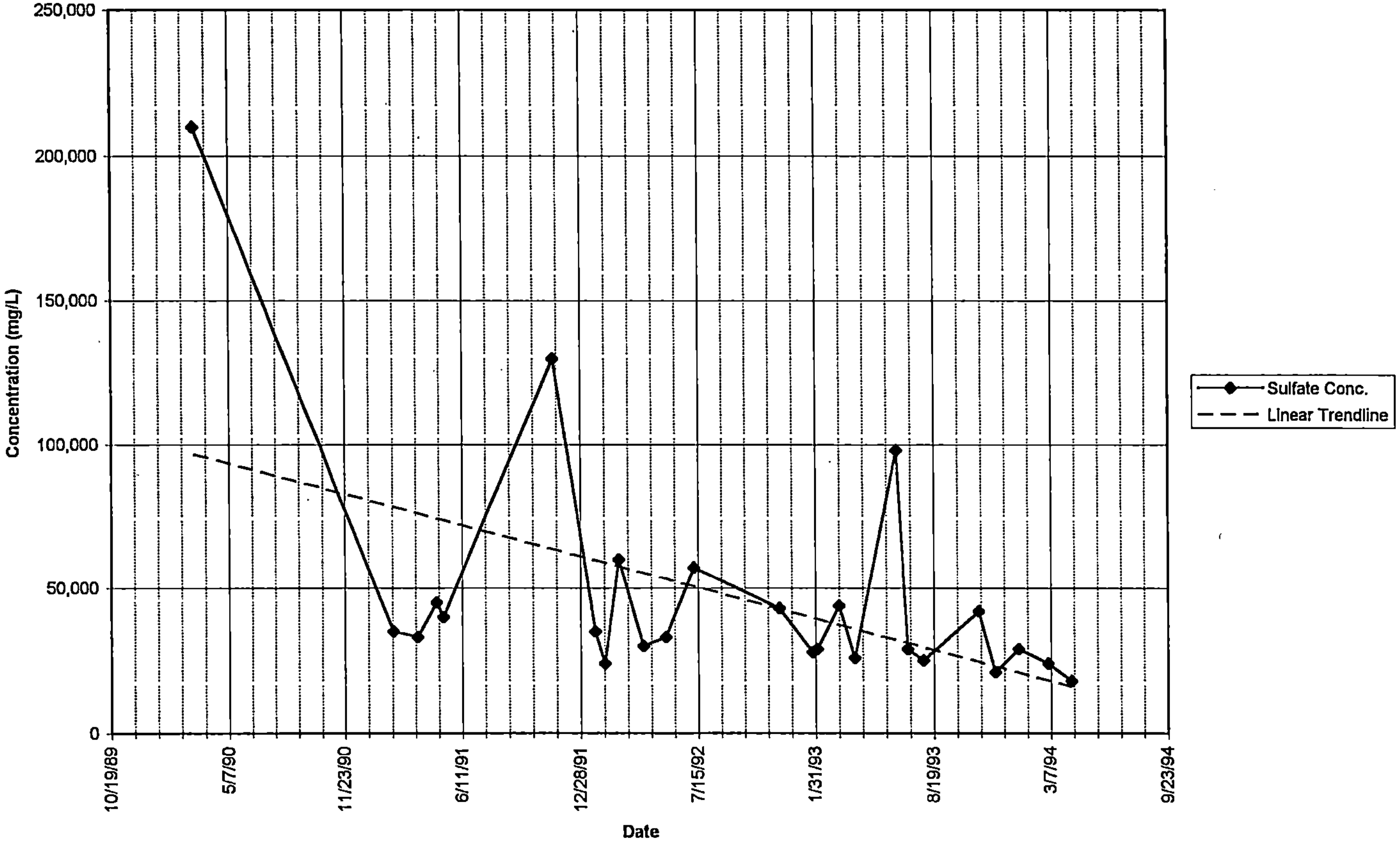
AGI
TECHNOLOGIES

Chloride Concentration at Location C - Garden Creek

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	6 Mar 95	JMM		

PLATE:
D8



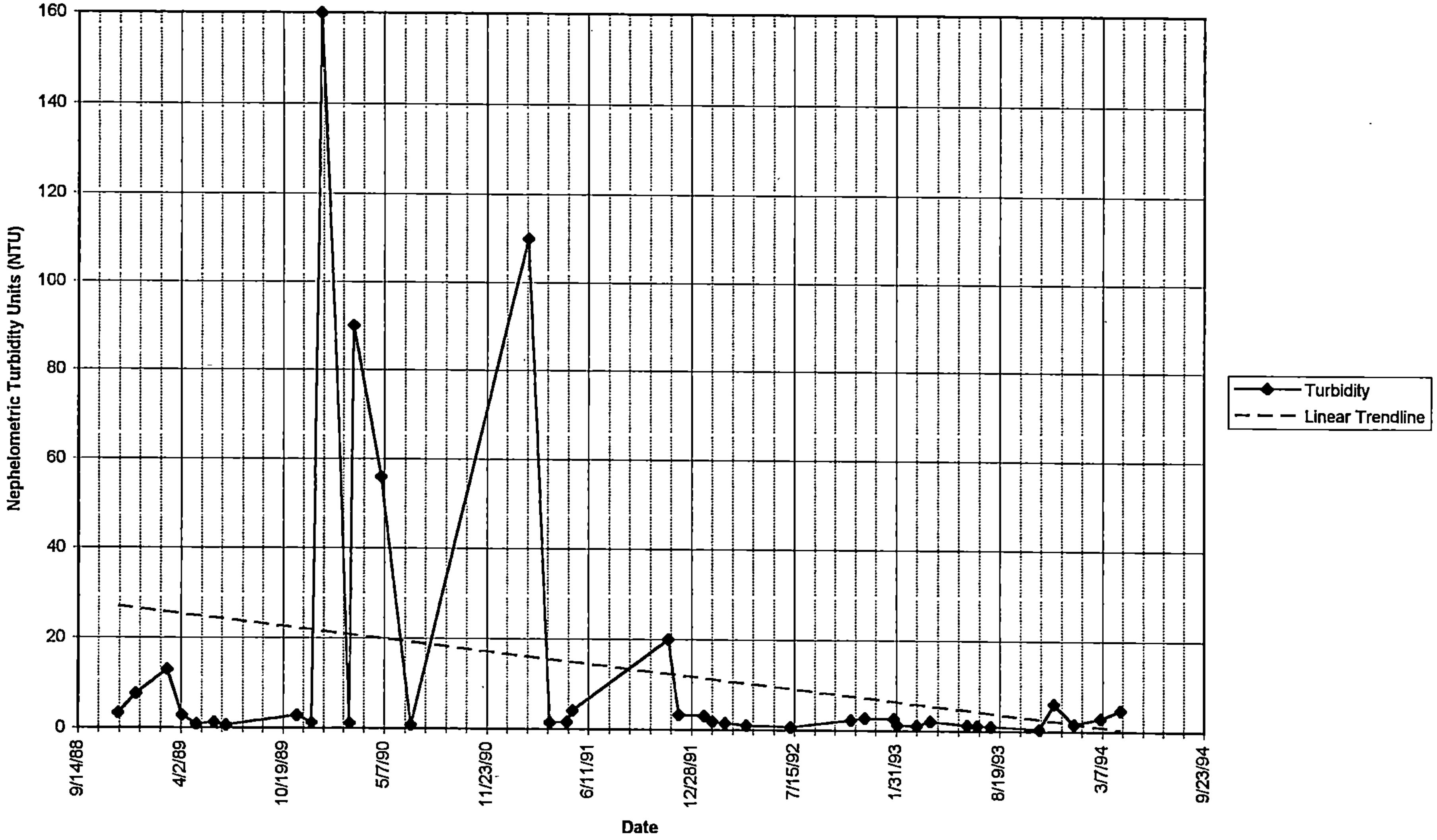
AGI TECHNOLOGIES

Sulfate at Location F - Garden Creek

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	6 Mar 95	TMM		

PLATE:
D9



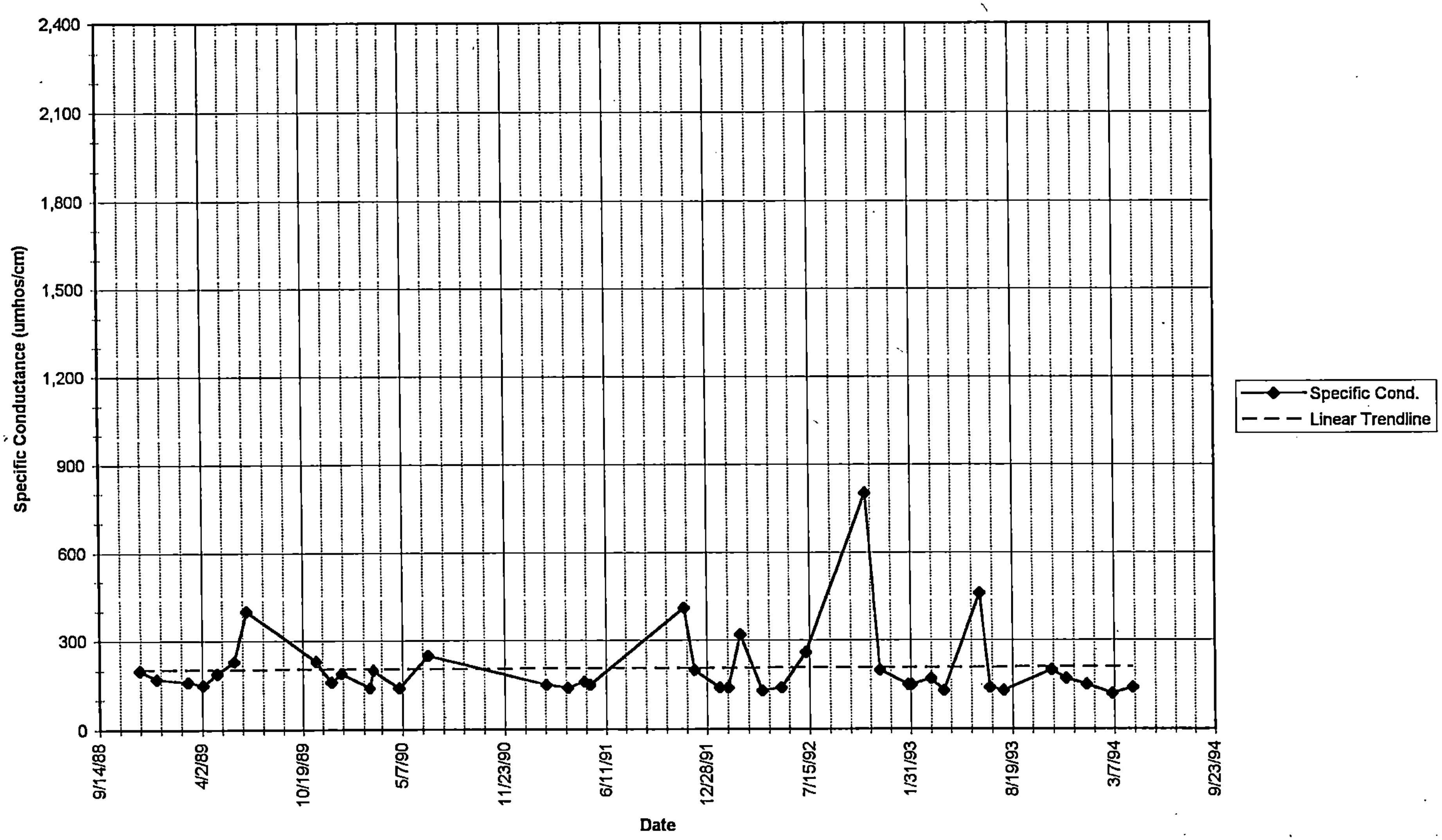
AGI
TECHNOLOGIES

Turbidity at Location F - Garden Creek

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

IPLATE
D10

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	6 Mar 95	TMM		



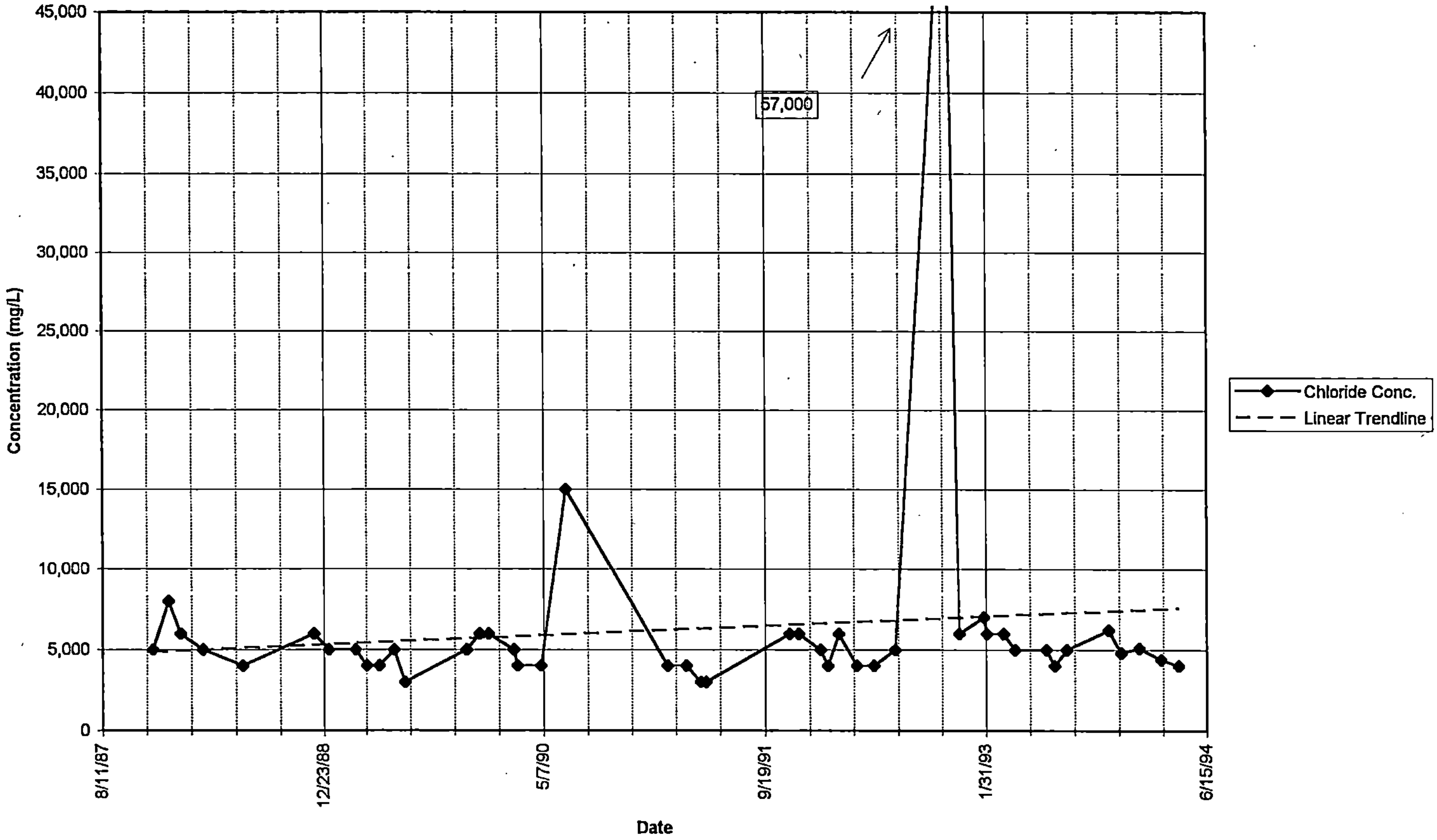
AGI
TECHNOLOGIES

Specific Conductance at Location F - Garden Creek

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PLATE
D11

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	6 Mar 95	TMM		



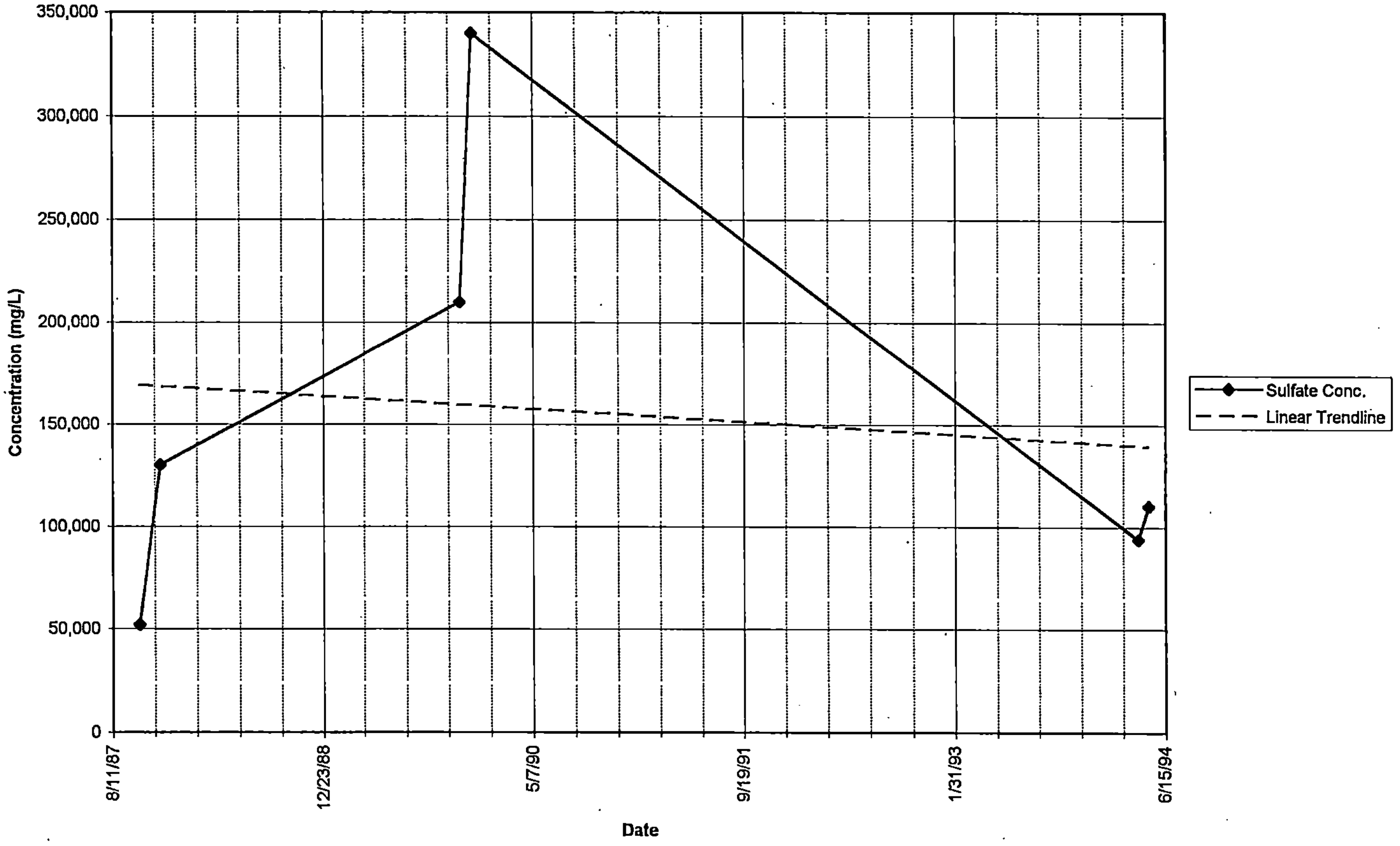
AGI TECHNOLOGIES

Chloride Concentration at Location F - Garden Creek

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PLATE
D12

PROJECT NO. 15,512.108
DRAWN DFF
DATE 6 Mar 95
APPROVED JMM
REVISED
DATE



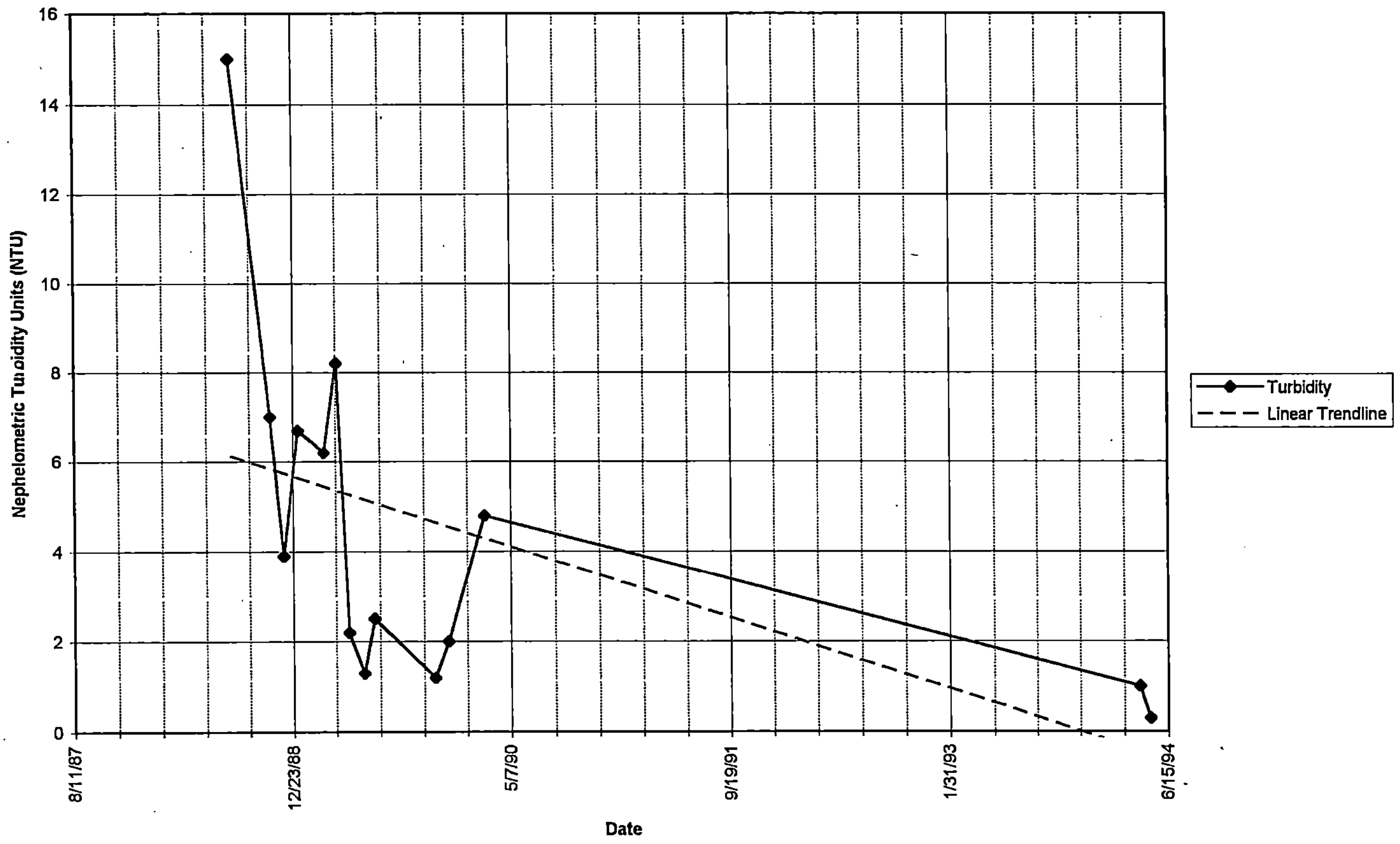
AGI
TECHNOLOGIES

Sulfate at Location D - Garden Creek

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	6 Mar 95	TMM		

PLATE
D13



AGI TECHNOLOGIES

Turbidity at Location D - Garden Creek

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PLATE
D14

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	6 Mar 95	TMM		

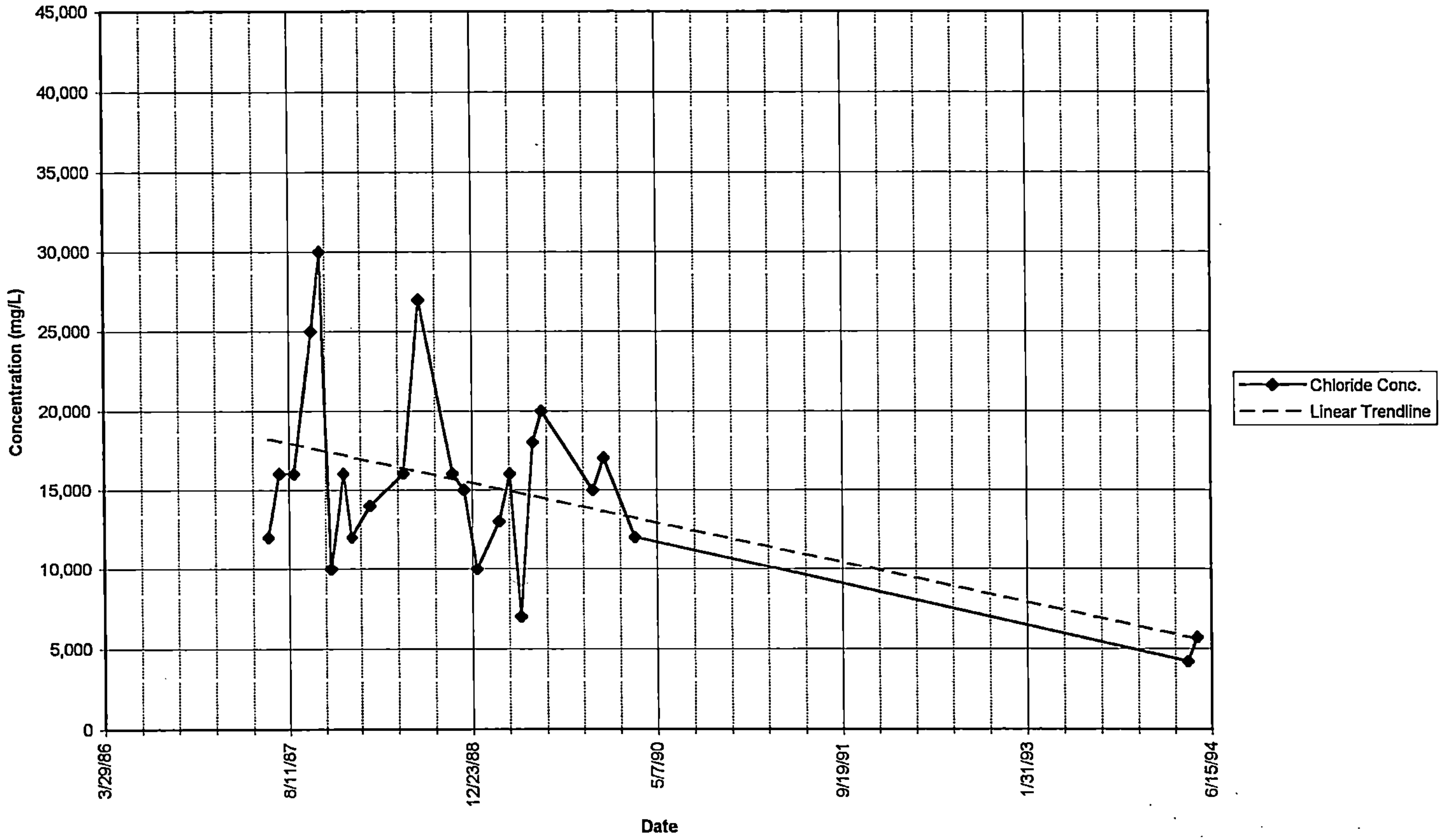
AGI
TECHNOLOGIES

Specific Conductance at Location D - Garden Creek

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PLATE
D15

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	6 Mar 95	TMM		



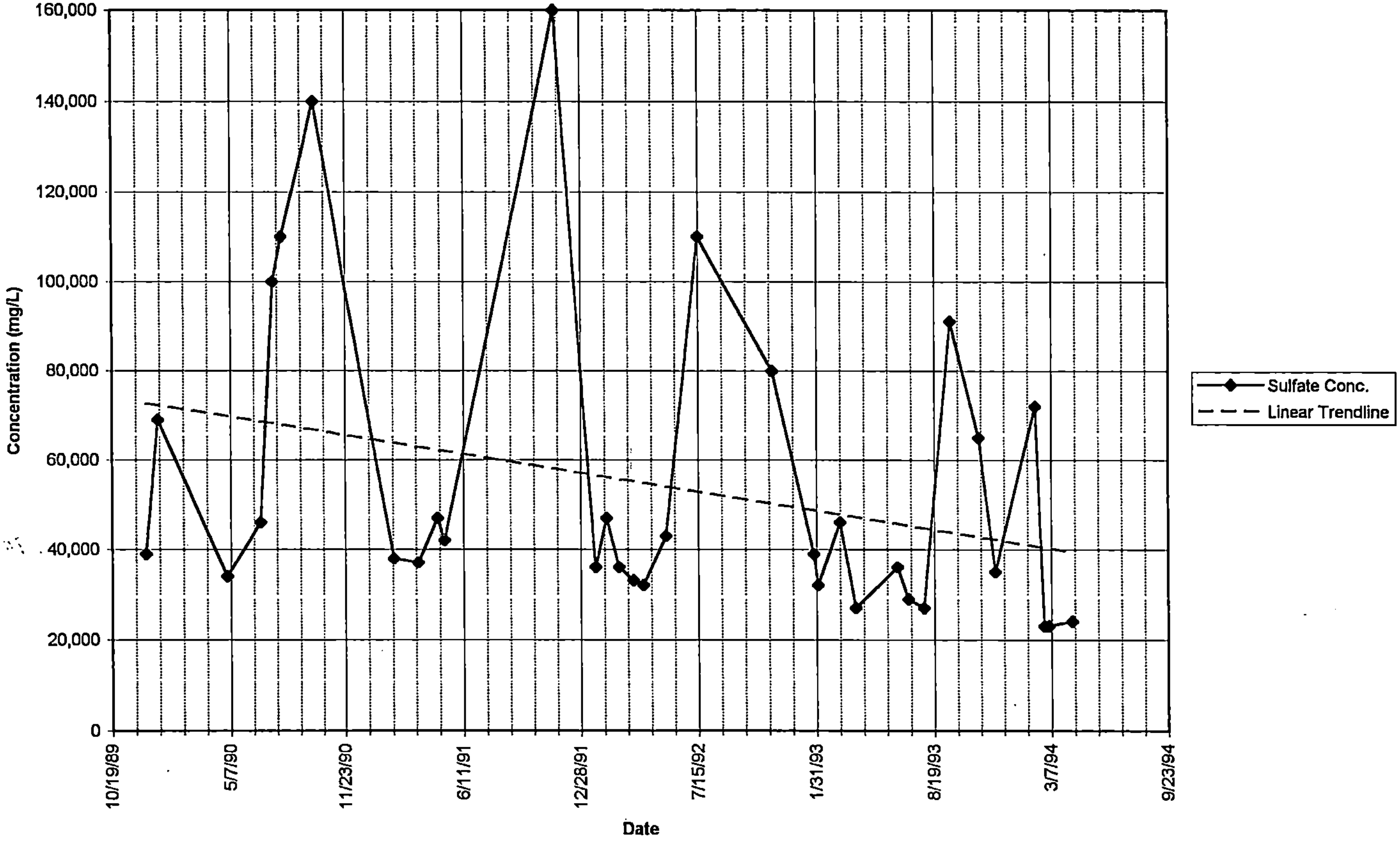
AGI
TECHNOLOGIES

Chloride Concentration at Location D - Garden Creek

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	6 Mar 95	TMM		

PLATE:
D16



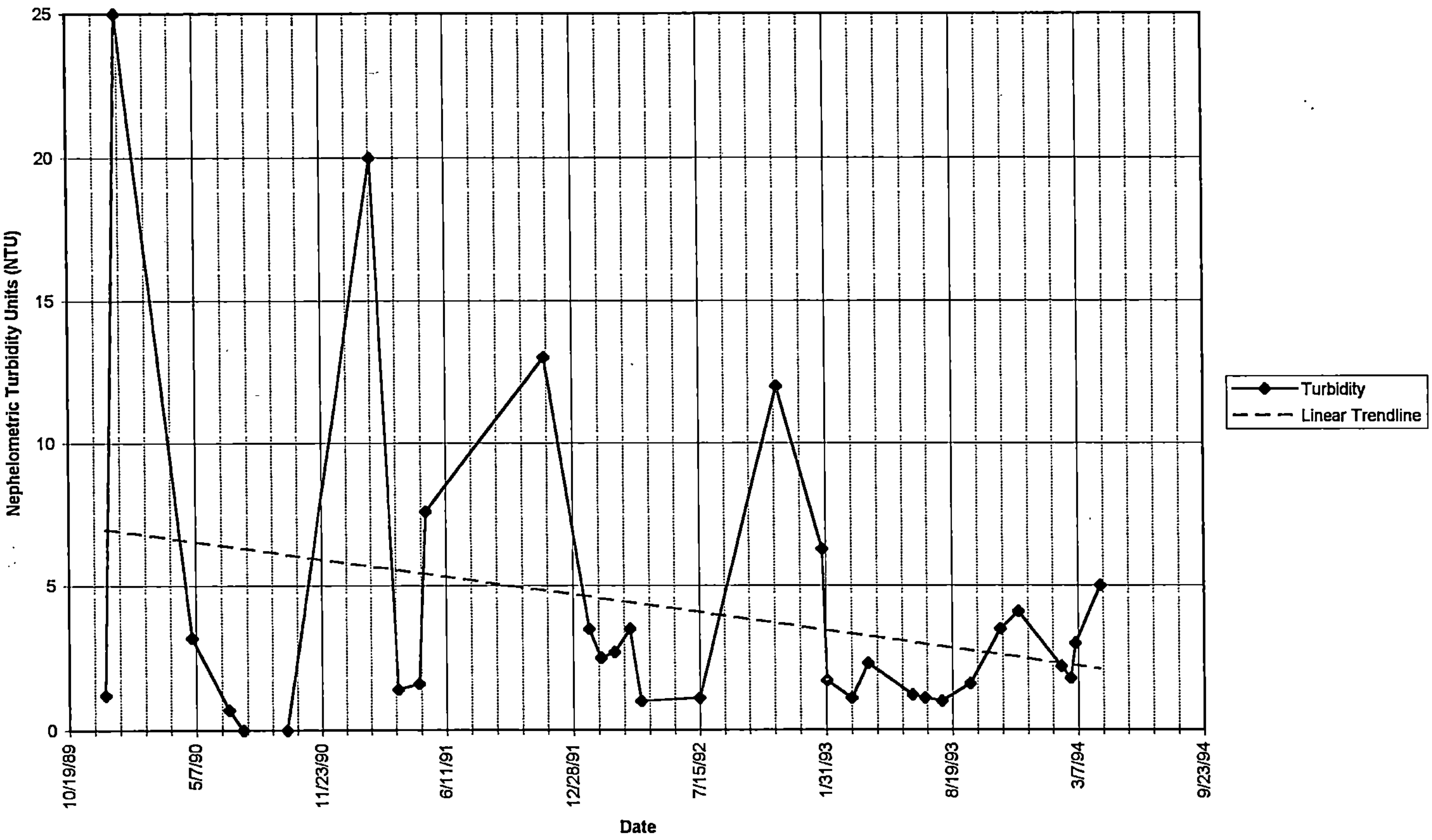
AGI
TECHNOLOGIES

Sulfate at Location J - Garden Creek

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PLATE:
D17

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	6 Mar 95	JMM		



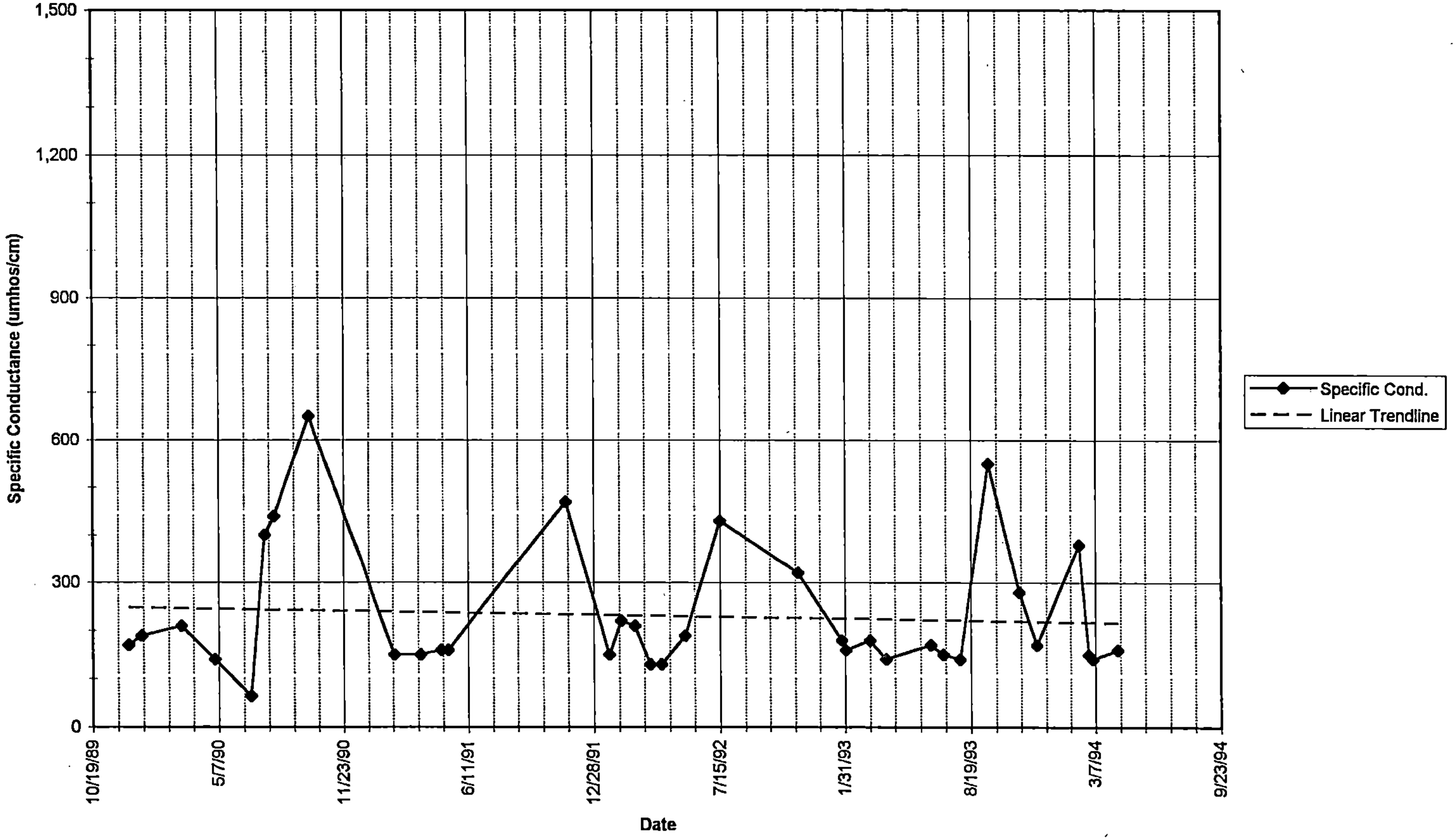
AGI
TECHNOLOGIES

Turbidity at Location J - Garden Creek

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PLATE:
D18

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	6 Mar 95	TMM		



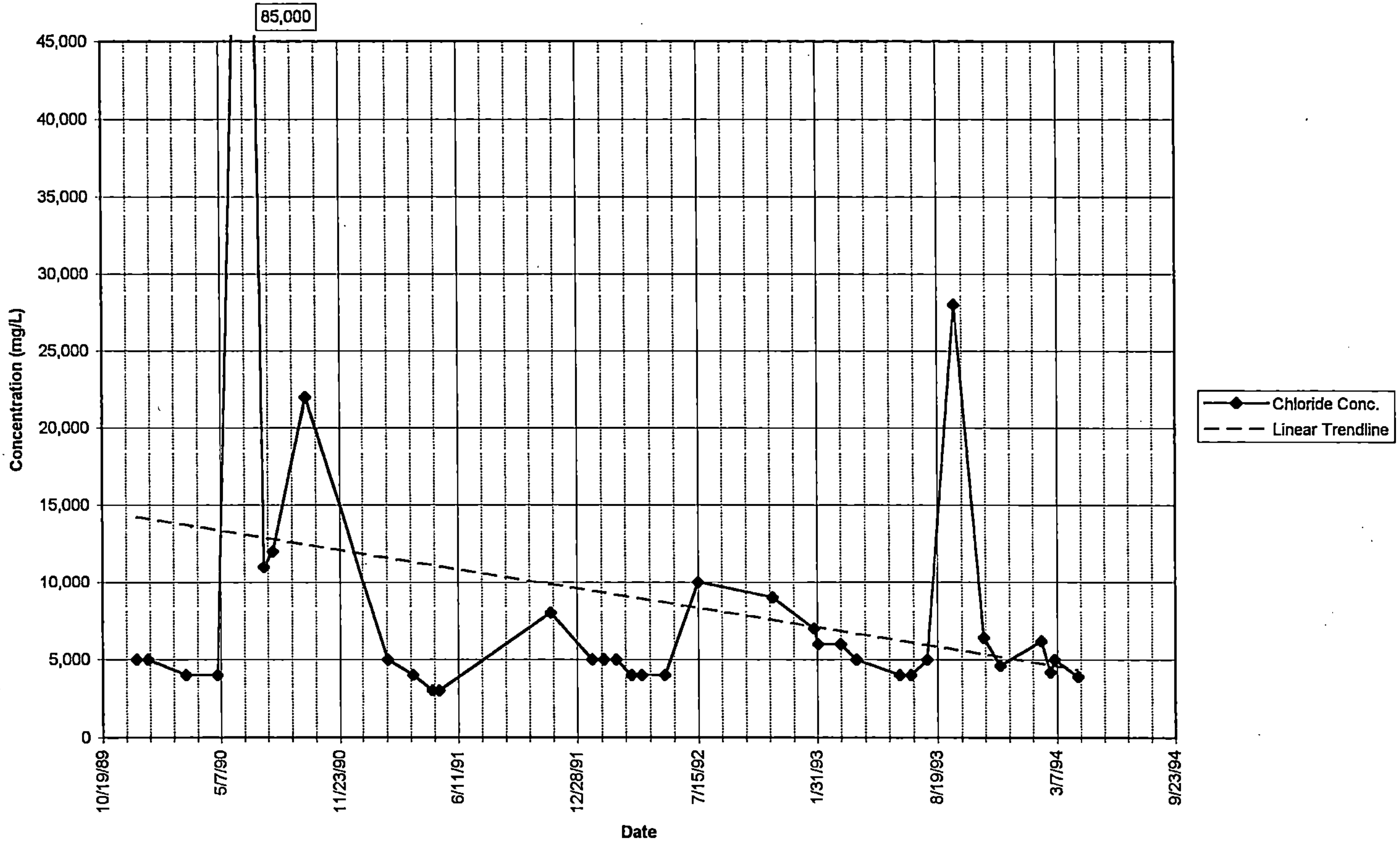
AGI
TECHNOLOGIES

Specific Conductance at Location J - Garden Creek

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	6 Mar 95	JMM		

PLATE:
D19



AGI
TECHNOLOGIES

Chloride Concentration at Location J - Garden Creek

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PLATE
D20

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	6 Mar 95	TMM		

APPENDIX E

Well Information and Groundwater Elevation and Flow Diagrams

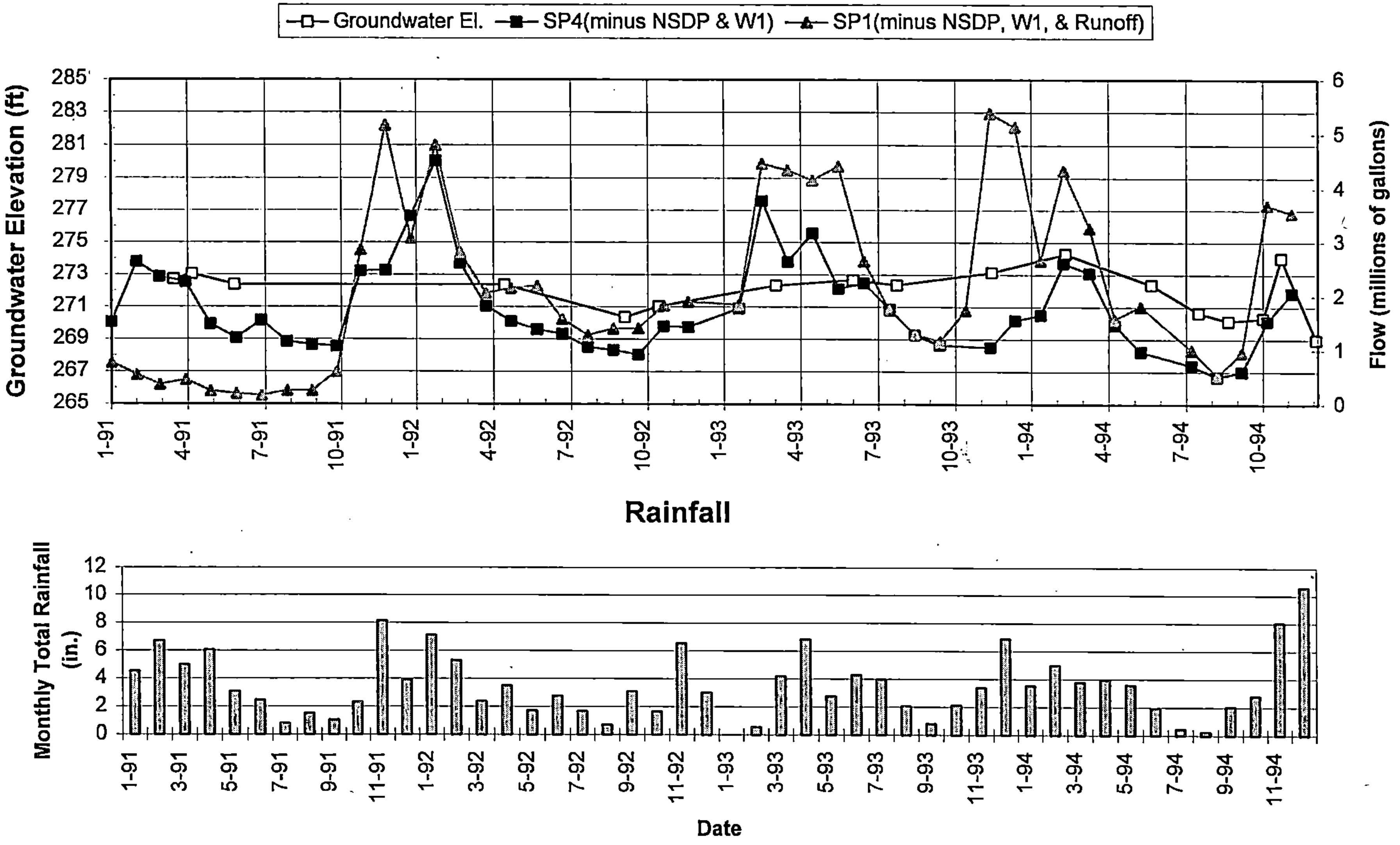
Table E–1
Well and Piezometer Coordinates and Reference Elevations

Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

	Coordinates		Top of Casing Elevation [a]
Well No.	Northing	Easting	(ft MSL)
G 1 A	321629.24	1324867.65	229.00
G 1 D	321638.17	1324885.65	229.96
G 2 D	321545.76	1325188.30	242.10
G 3	321467.49	1325426.66	270.37
G 4	320273.18	1324618.21	285.22
G 4 S	320264.49	1324668.28	286.52
G 5 A	321318.36	1325073.57	241.01
G 6 A	321441.59	1324948.06	242.51
G 6 B	321426.79	1324942.96	246.24
G 7 D	318161.15	1324644.56	336.10
G 7 S	318172.26	1324643.30	335.66
G 8 D1	321817.92	1325164.62	222.02
G 8 D2	321817.22	1325182.63	221.62
G 9 D	321275.75	1325193.71	274.60
G 9 S	321273.63	1325177.96	273.08
G 10 D	321254.31	1324950.50	268.32
G 10 S	321254.03	1324925.32	266.94
G 11 S	321467.94	1324722.20	250.74
G 12 D	320695.94	1324718.72	285.28
G 13 D	321600.06	1324674.85	232.17
G 14 D	319998.52	1325720.47	329.58
G 14 S	320002.03	1325710.77	328.76
G 15 S	318137.72	1325752.35	327.13
G 16 S	321332.98	1325019.89	238.90
W1	321336.65	1325043.79	239.07
W2	321330.53	1325081.10	238.78
PZ1	320849.23	1325615.77	318.84
PZ2	320434.25	1325607.60	319.63
PZ3	319617.98	1325603.21	324.18
PZ4	318983.87	1325600.88	323.18
PZ5	318487.52	1325367.24	311.16
PZ6	318491.00	1325253.97	311.96
PZ7	318527.91	1325036.29	311.16

Notes:

a) Elevations referenced to Mean Sea Level of NGVD 1929.



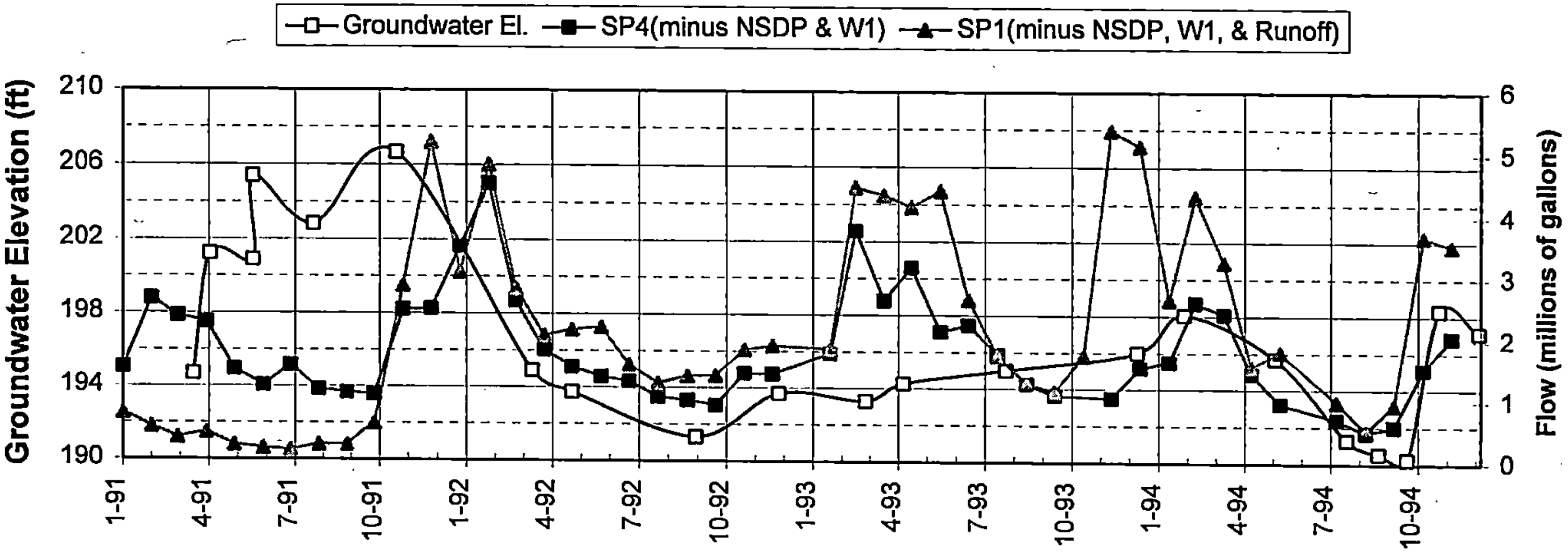
AGI
TECHNOLOGIES

Groundwater Elevation with Precipitation - Well G-4A

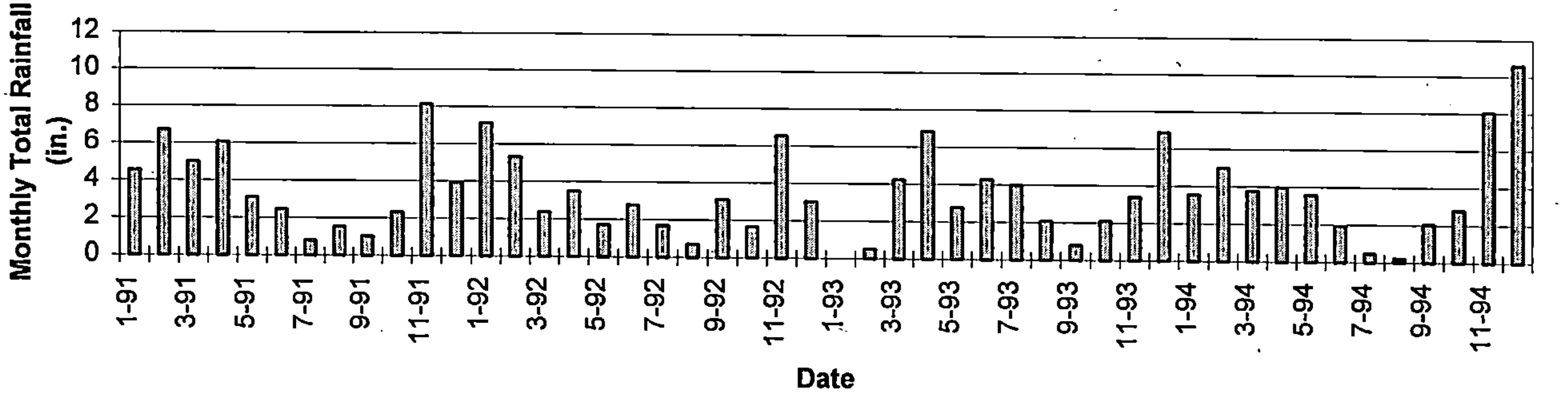
Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95	TMM		

PLATE
E-1



Rainfall



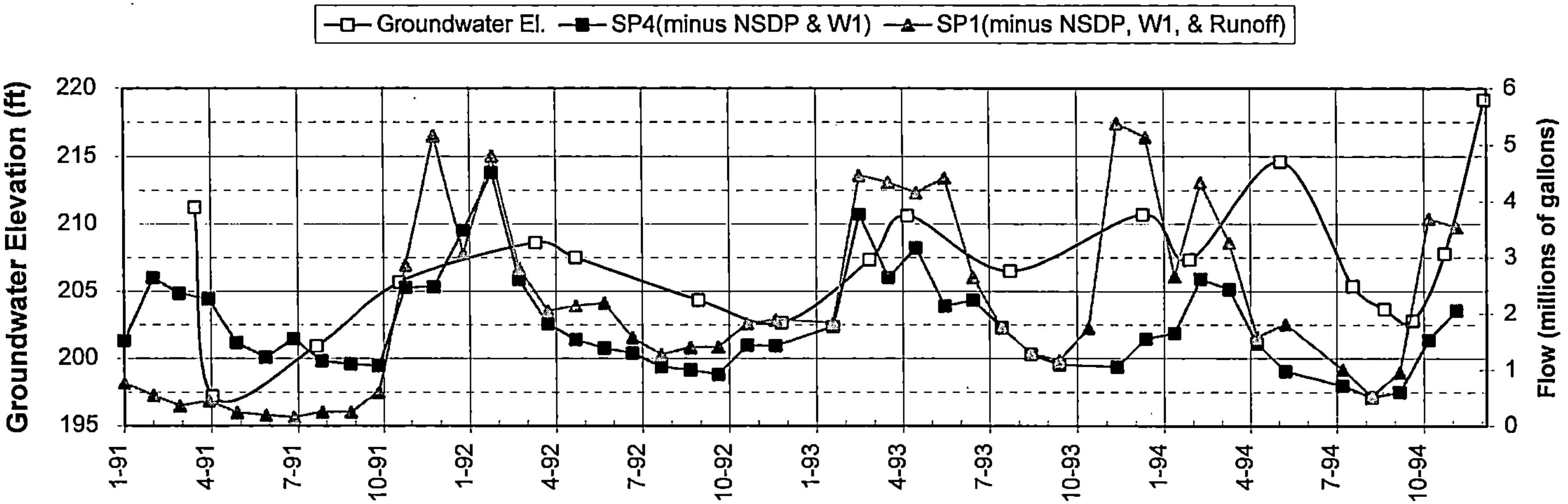
AGI TECHNOLOGIES

Groundwater Elevation with Precipitation - Well G-8D1

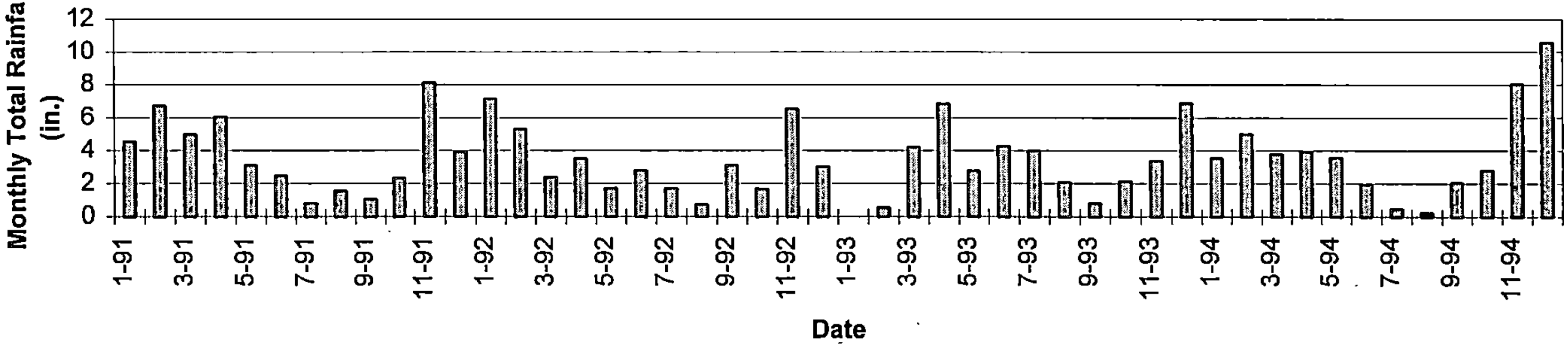
Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95	TMM		

PLATE
E-2



Rainfall



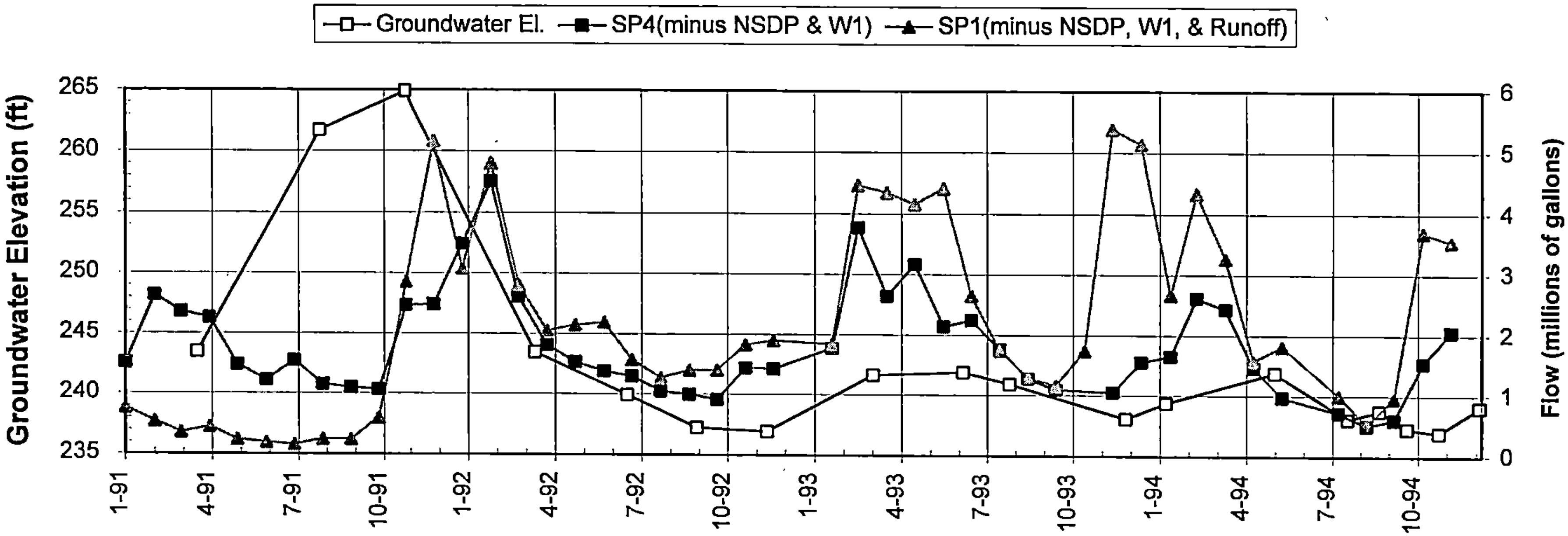
AGI
TECHNOLOGIES

Groundwater Elevation with Precipitation - Well G-8D2

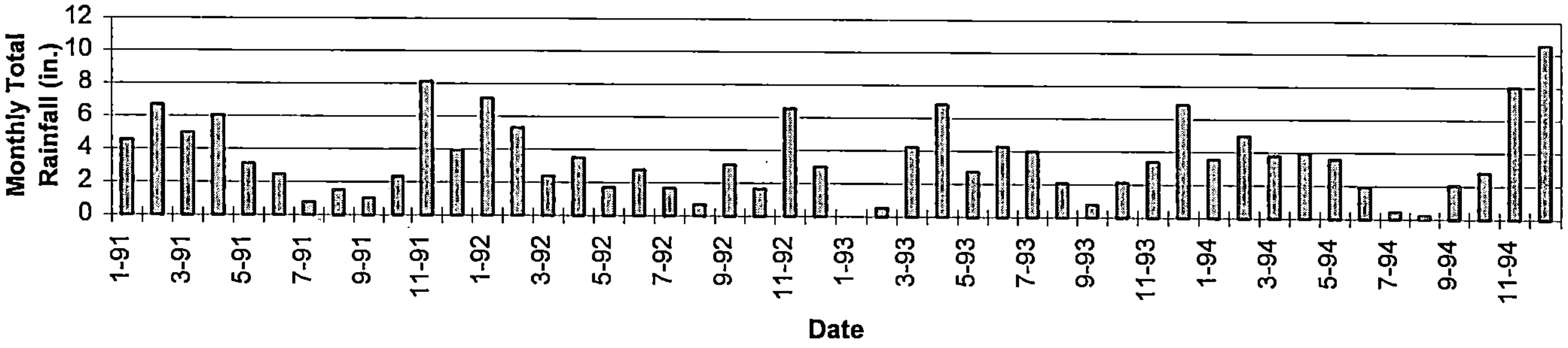
Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95	TMM		

PLATE
E-3



Rainfall



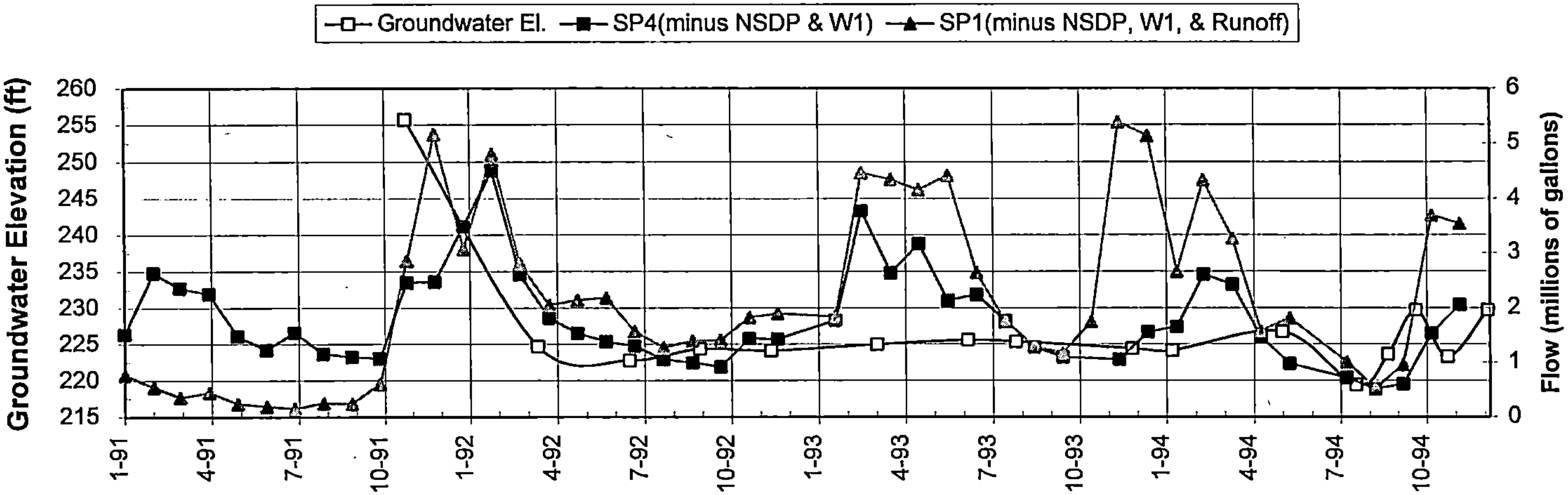
AGI
TECHNOLOGIES

Groundwater Elevation with Precipitation - Well G-9S

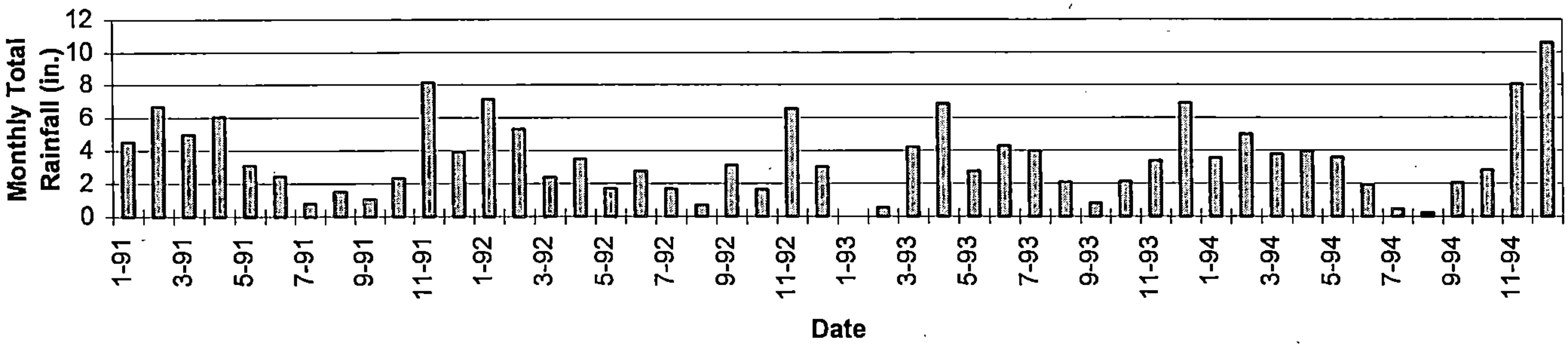
Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95	TMM		

PLATE
E-4



Rainfall



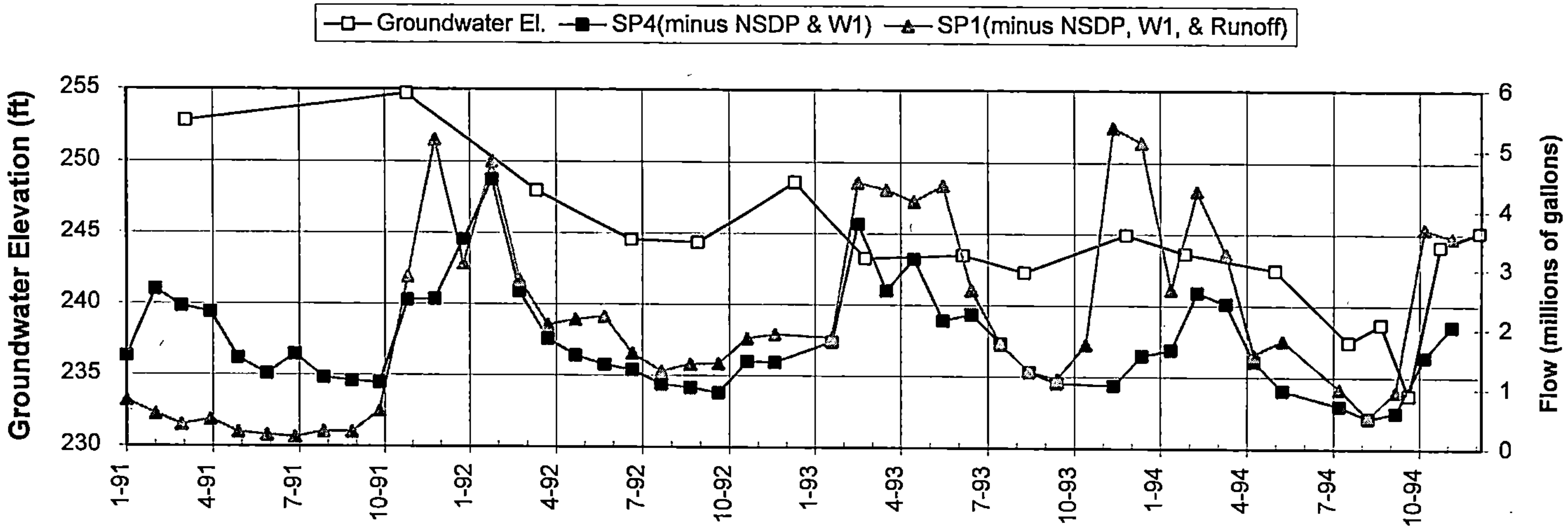
AGI TECHNOLOGIES

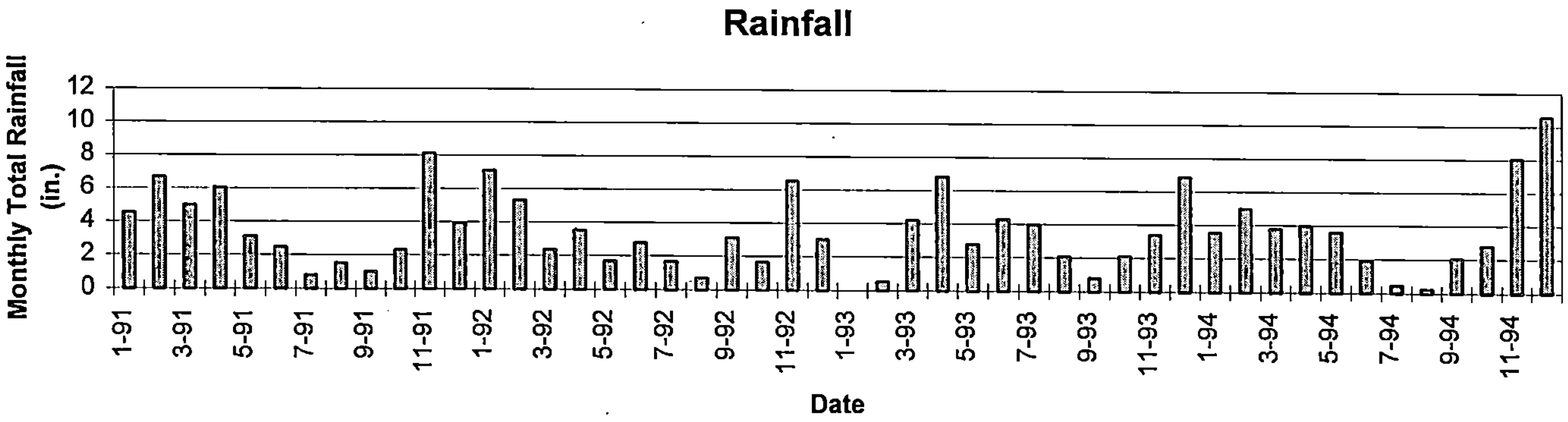
Groundwater Elevation with Precipitation - Well G-9D

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PLATE
E-5

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95	TMM		




Rainfall

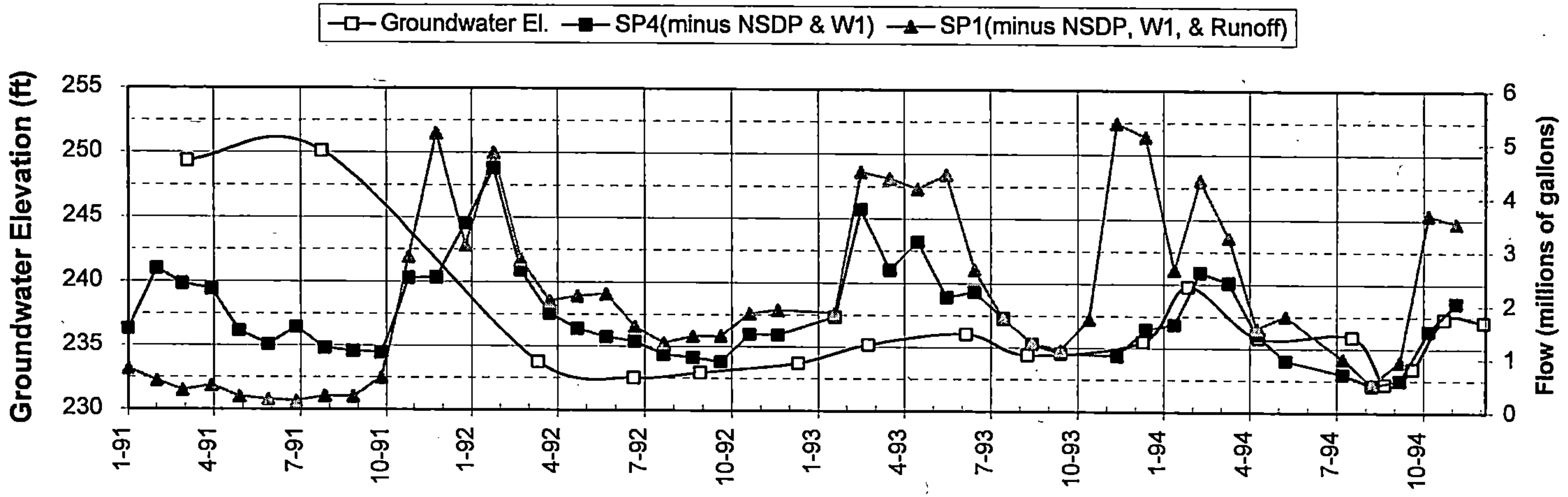
AGI
TECHNOLOGIES

Groundwater Elevation with Precipitation - Well G-10S

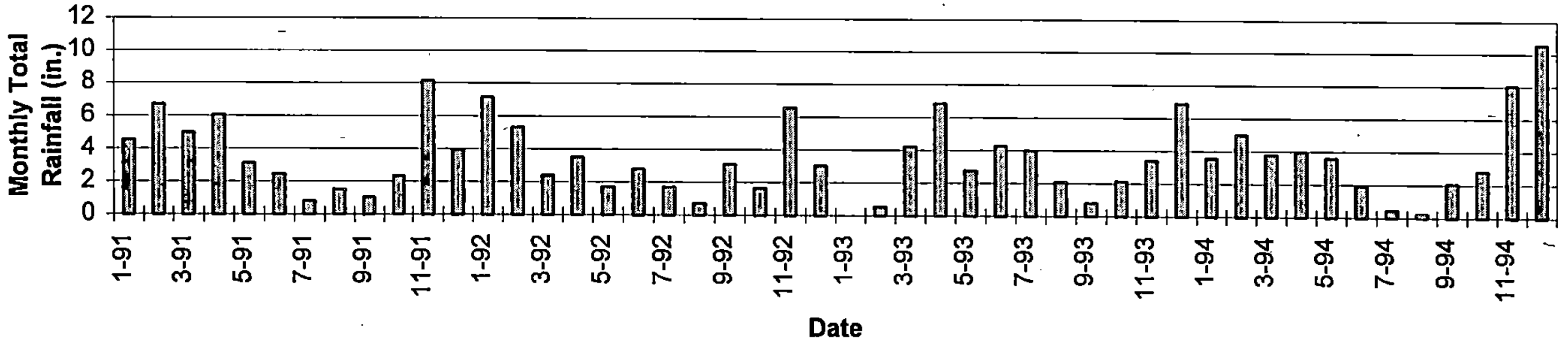
Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PLATE
E-6

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95	TMM		



Rainfall



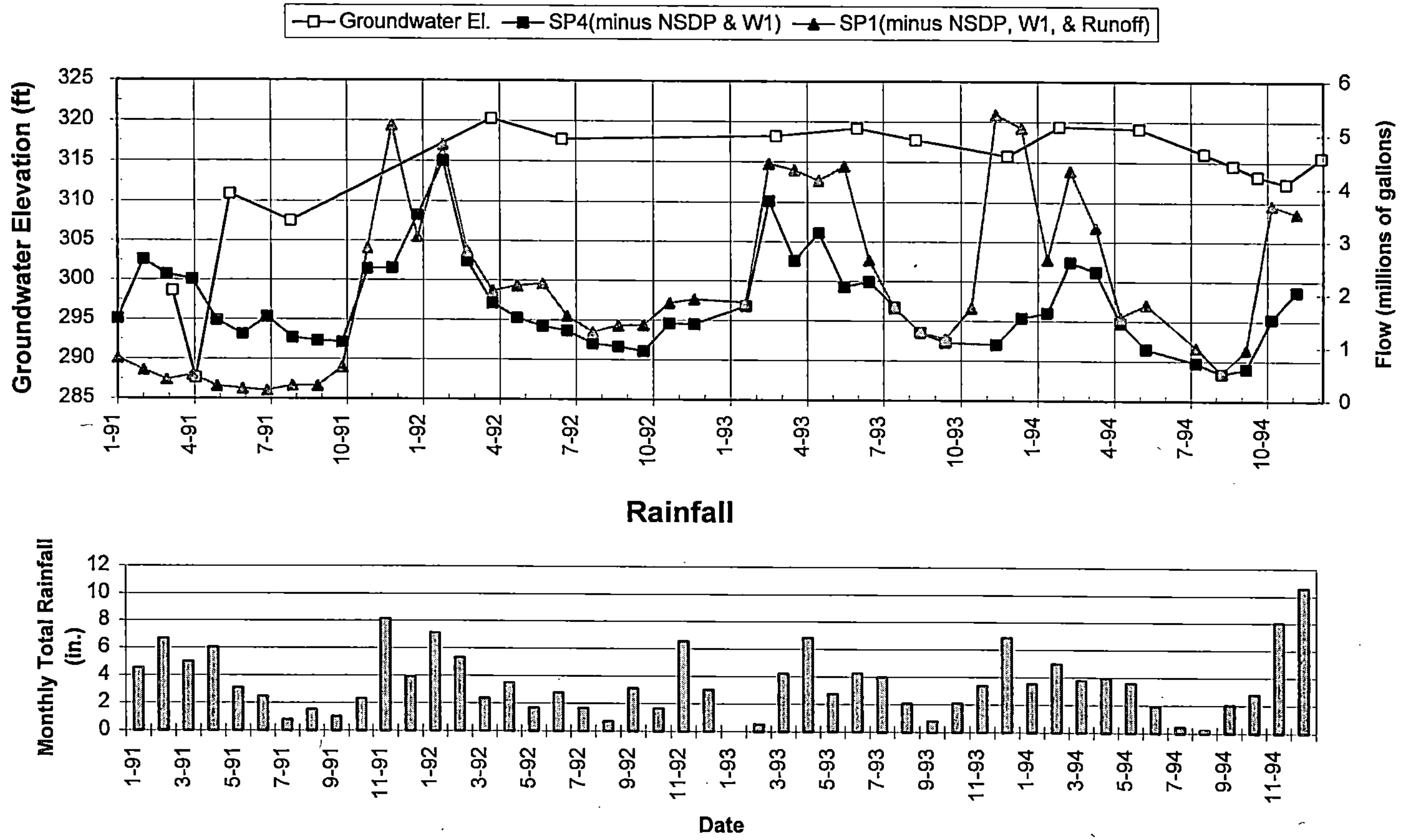
AGI
TECHNOLOGIES

Groundwater Elevation with Precipitation - Well G-10D

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95	TMM		

PLATE
E-7



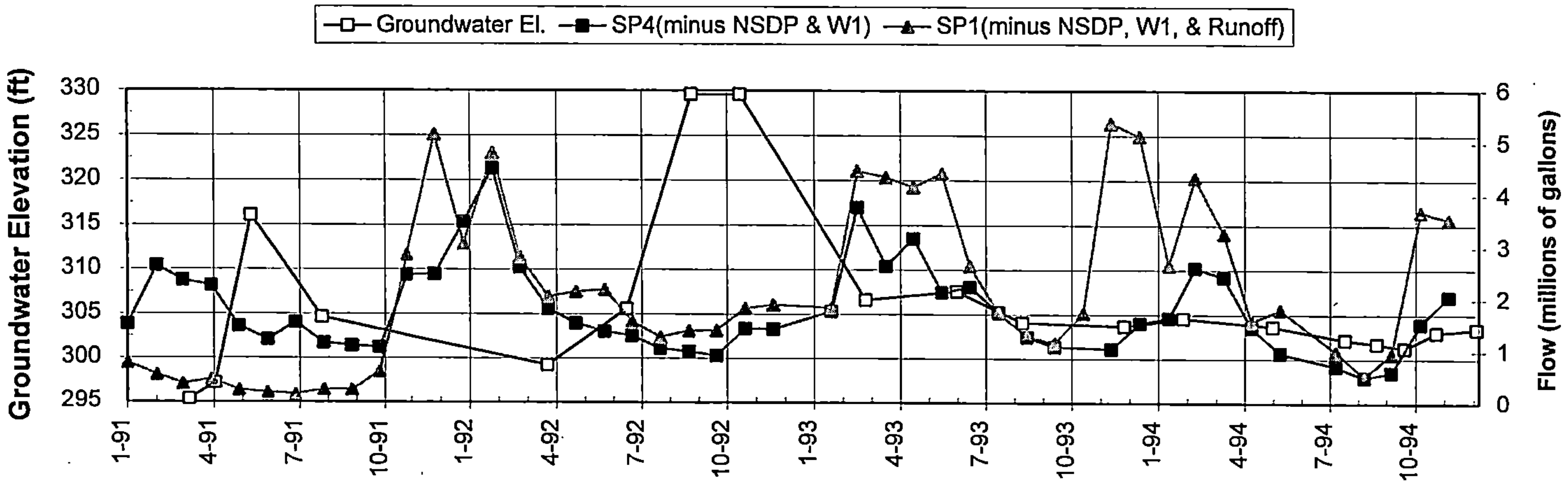
AGI
TECHNOLOGIES

Groundwater Elevation with Precipitation - Well G-14S

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95			

PLATE
E-8



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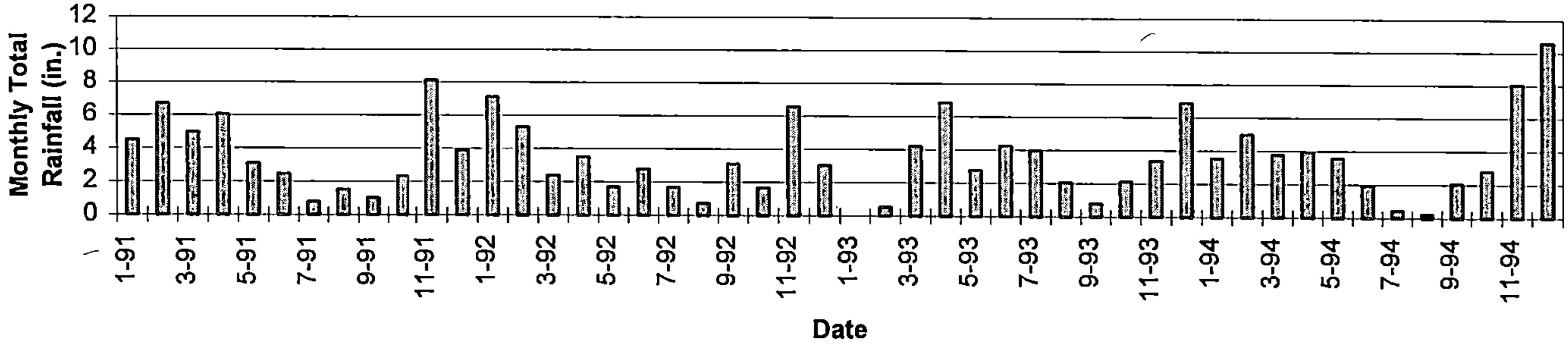


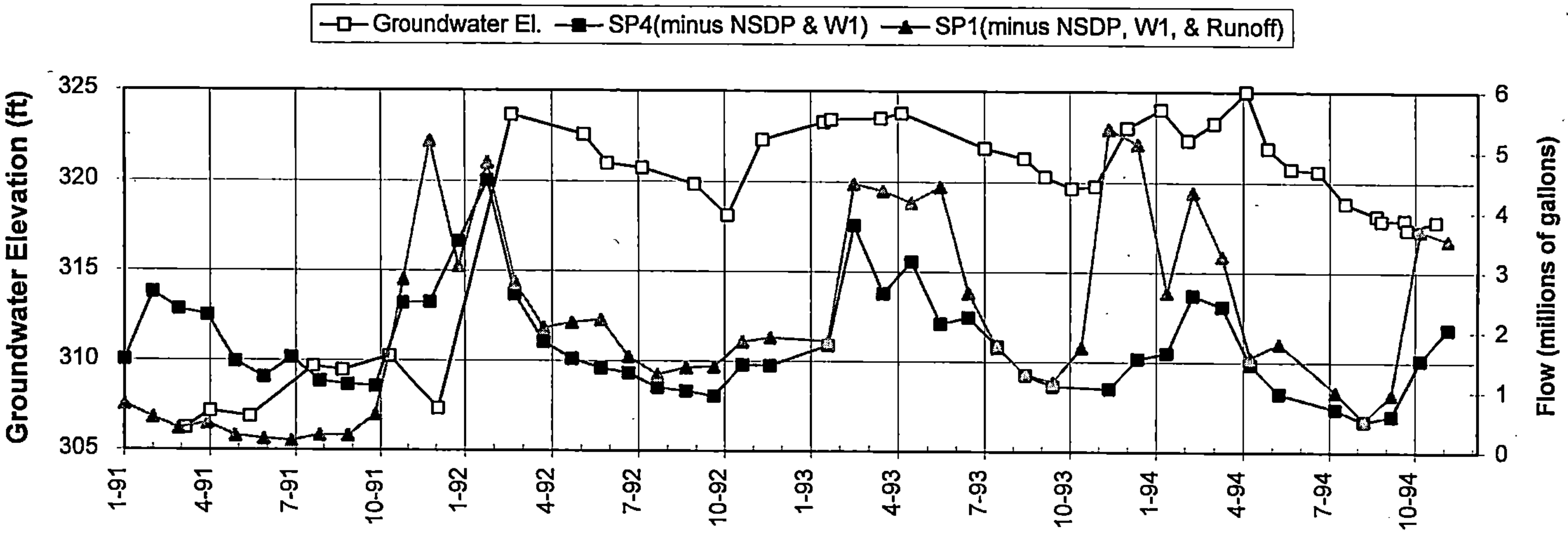
AGI
TECHNOLOGIES

Groundwater Elevation with Precipitation - Well G-14D

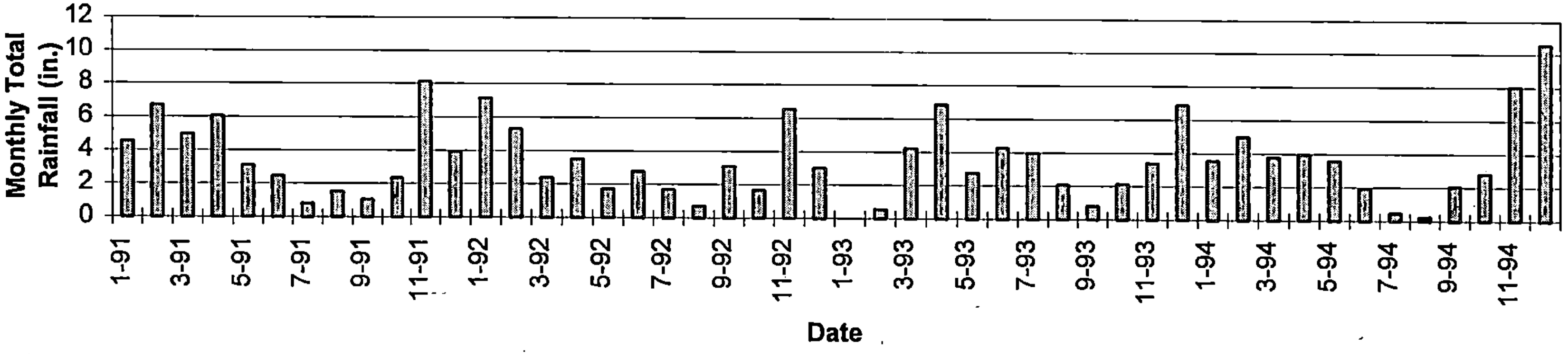
Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PLATE
E-9

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95	JMM		



Rainfall



AGI TECHNOLOGIES

Groundwater Elevation with Precipitation - Well G-15S

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PLATE
E-10

PROJECT NO. 15,512.108
DRAWN DFF
DATE 7 Mar 95
APPROVED TMM
REVISED
DATE

APPENDIX F

Groundwater Chemistry Evaluation and Quality Assurance

APPENDIX F

Groundwater Chemistry Evaluation and Quality Assurance

AGI Technologies (AGI) evaluated groundwater chemistry trends based on plots of concentration with time provided by Snohomish County (the County). Detection limits were not available and our evaluation is therefore based primarily on direct interpretation of the plots.

Upgradient (background) trends were used for comparison to the extent possible to identify potential impacts on groundwater chemistry downgradient of Cathcart Landfill. G-15S and G-7D were considered background wells for the shallow and deep groundwater zones, respectively.

The following assumptions were made to evaluate the groundwater chemistry plots provided by the County.

- Chloride Ln detection limit is 0 over time period evaluated.
- Sulfate Ln detection limit is 0 over time period evaluated.
- Nitrate values below -2.3 are assumed to be in error and have been adjusted to -2.3 for comparison purposes.
- Ammonia Ln detection limit is -4.6 over time period evaluated.
- Arsenic Ln detection limit is -5.99 over time period evaluated.
- Barium Ln detection limit is -4.6, then becomes -6.5.
- Chromium Ln detection limit is -5.99 over time period evaluated.
- Cadmium Ln detection limit is 0, then becomes -6.9.
- Lead Ln detection limit is -5.9, then -5.32, then -7.6".
- Mercury Ln detection limit is -9.9, then becomes 0.
- Zinc Ln detection limit is -6.9 over time period evaluated.
- Total coliform Ln detection limit is 0 over time period evaluated.

The following summarizes chemical analyte-specific trends noted in groundwater chemistry over the time period March 1988 through May 1994 for monitoring wells at the landfill. Gross trends are observed in concentration versus time plots provided by the County. **Plates F-1** through **F-7** are plots of shallow zone groundwater chemical concentrations over the review period for G-1A, G-6A, G-8D1, G-9S, G-10S, and G-15S; **Plates F-8** through **F-14** plot deep zone groundwater chemistry data for G-1D, G-6B, G-7D, G-8D2, G-9D, and G-10D. Well specific chemical trends over the referenced time period are as follows:

SHALLOW GROUNDWATER ZONE WELLS

G-15S (Background): Chloride concentrations have become *higher* since approximately July 1993.
Sulfate *increases.*
Ammonia *decreases.*
Chromium *decreases.*
Total coliform *decreases* to non-detection.

G-01A: Sulfate *increases.*

G-4: No available data after June 1992.

G-04A: Chloride *increases.*

G-5A:	No available data after 1989.
G-6A:	Chloride *increases* slightly.
	Conductivity *decreases* very slightly.
G-6S:	No data after November 1991.
G-7S:	Zinc *decreases.*
G-08D1:	Chloride *increases.*
	Conductivity *increases.*
G-09S:	Chloride *increases.*
	Sulfate *increases.*
	Conductivity *increases* slightly.
G-10S	Chloride *increases.*
	Sulfate possible *increase.*
	Conductivity *increases.*
	Ammonia *increases.*
	Zinc possible slightly *increase.*
	Total coliforms show higher concentrations and erratic.
G-11S:	Chloride *increases.*
	Nitrate *decreases.*
	Zinc *increases.*
G-14S:	Chloride *increases.*
	Nitrate *increases.*

DEEP GROUNDWATER ZONE WELLS

G-07D (Background):	Chloride has been detected since September 1993.
	Conductivity *increases* slightly.
	Arsenic has been detected since approximately January 1993.
	Chromium *decreases* to non-detection during last 3 rounds of available data.
	Metals generally peaked early 1991 to August 1991.
	Zinc appears to *decrease* since January 1992.
G-01D:	Chloride concentrations *higher* after landfill closure.
	Nitrate concentrations *higher* after landfill closure.
	Arsenic decreases.
	Total coliform hits are *higher* after landfill closure.
G-02D:	Nitrate *increased* until September 1993, then *decreased* during last 4 rounds of data reviewed.
	Total coliform concentrations become *higher* after January 1991.
G-06B:	Chloride *increases.*
	Sulfate *increases.*
	Nitrate generally *increases.*
	Ammonia *decreases.*
	Lead *decreased* to non-detection during last 3 rounds of data reviewed.
	Zinc *decreases.*
G-06D:	Not sampled after November 1991.
G-09D:	Ammonia slightly *increases.*
	Zinc concentration appears to cycle.
G-10D:	Chloride *increases* since October 1989.
	Ammonia *increases* since October 1990.

G-12D: Chloride *increases* since early 1991.
Sulfate *increases* very slightly.
G-13D: Chloride *increases* slightly during last 3 rounds.
G-14D: Chloride *increases.*
Arsenic appears to *decrease* slightly.
Barium *decreases* slightly.

Groundwater chemistry results for the fourth quarter 1994 round are presented in **Tables F-1, F-2,** and **F-3.**

Table F–1
General Parameters – Groundwater
Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Parameter	Detection Limit	Date Sampled	Sample I.D.								
			G–1A	G–1D	G–2D	G–3	G–4A	G–6A	G–6B	G–7S	G–7D
pH		10/94	NA	NA	NA	NA	5.8	NA	7.8	6.1	9.1
		11/94	NA	8.8	8.7	NA	NA	5.0	7.7	6.3	9.3
		12/94	7.3	NA	NA	7.7	NA	5.4	8.0	6.5	9.4
Total Organic Cargon (mg/L)	1.0	10/94	NA	NA	NA	NA	ND	NA	ND	5.8	1.2
	1.0	11/94	NA	1.7	ND	NA	NA	NA	NA	NA	NA
	1.0	12/94	NA	NA	NA	NA	NA	NA	NA	NA	NA
Chemical Oxygen Demand (mg/L)	10	10/94	NA	NA	NA	NA	22	NA	29	32	ND
	10	11/94	NA	11	ND	NA	NA	NA	NA	NA	NA
	10	12/94	NA	NA	NA	NA	NA	NA	NA	NA	NA
Chloride (mg/L)	1.0	10/94	NA	NA	NA	NA	5.4	NA	37	1.9	1.9
	1.0	11/94	NA	18	5.5	NA	NA	9.4	28	2.0	2.4
	1.0	12/94	1.5	NA	NA	7.5	NA	9.4	33	2.1	2.1
Conductivity (μmhos/cm)	0.5	10/94	NA	NA	NA	NA	550	NA	1,700	500	630
	0.5	11/94	NA	940	570	NA	NA	960	1,700	650	630
	0.5	12/94	340	NA	NA	290	NA	650	1,500	540	580
Ammonia Nitrogen (mg/L)	0.005	10/94	NA	NA	NA	NA	0.009	NA	0.027	0.028	0.12
	0.005	11/94	NA	0.20	0.15	NA	NA	NA	NA	NA	NA
	0.005	12/94	NA	NA	NA	NA	NA	NA	NA	NA	NA
Nitrate + Nitrite Nitrogen (mg/L)	0.01	10/94	NA	NA	NA	NA	ND	NA	0.68	ND	0.71
	0.01	11/94	NA	ND	7.3	NA	NA	NA	NA	NA	NA
	0.01	12/94	NA	NA	NA	NA	NA	NA	NA	NA	NA
Nitrite Nitrogen (mg/L)	0.001	10/94	NA	NA	NA	NA	0.006	NA	0.001	ND	0.035
	0.001	11/94	NA	0.005	0.012	NA	NA	NA	NA	NA	NA
	0.001	12/94	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table F−1
General Parameters − Groundwater

Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Parameter	Detection Limit	Date Sampled	Sample I.D.								
			G−1A	G−1D	G−2D	G−3	G−4A	G−6A	G−6B	G−7S	G−7D
Sulfate (mg/L)	10	10/94	NA	NA	NA	NA	67	NA	200	150	100
	10	11/94	NA	46	100	NA	NA	420	240	270	71
	10	12/94	78	NA	NA	38	NA	260	300	240	78
Total Coliforms (cfu/100 ml)	1	10/94	NA	NA	NA	NA	3	NA	<2	ND	ND
	1	11/94	NA	4	2	NA	NA	NA	NA	NA	NA
	1	12/94	NA	NA	NA	NA	NA	NA	NA	NA	NA
Turbidity (NTU)	10	10/94	NA	NA	NA	NA	NA	NA	NA	NA	NA
	10	11/94	NA	NA	NA	NA	NA	NA	NA	NA	NA
	10	12/94	NA	NA	NA	NA	NA	NA	37	26	31

Notes:

ND − Not detected.
mg/L − Milligrams per liter.
μmhos/cm − Micromhos per centimeter.

Table F–1
General Parameters – Groundwater
Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Parameter	Detection Limit	Date Sampled	Sample I.D.								
			G–8D1	G–8D2	G–9S	G–9D	G–10S	G–10D	G–11S	G–12	G–12D
pH		10/94	NA	NA	NA	NA	NA	NA	NA	NA	8.9
		11/94	NA	NA	NA	NA	NA	NA	NA	NA	9.0
		12/94	9.3	9.5	8.6	8.6	6.5	6.8	2.7	9.2	
Total Organic Cargon (mg/L)	1.0	10/94	NA	NA	NA	NA	NA	NA	NA	NA	ND
	1.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA	23
	1.0	12/94	NA	NA	ND	ND	ND	3.2	NA	NA	NA
Chemical Oxygen Demand (mg/L)	10	10/94	NA	NA	NA	NA	NA	NA	NA	NA	NA
	10	11/94	NA	NA	NA	NA	NA	NA	NA	NA	NA
	10	12/94	NA	NA	19	15	41	32	NA	NA	NA
Chloride (mg/L)	1.0	10/94	NA	NA	NA	NA	NA	NA	NA	NA	6.4
	1.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA	6.1
	1.0	12/94	3.5	3.7	7.8	16	87	80	34	6.0	NA
Conductivity (μmhos/cm)	0.5	10/94	NA	NA	NA	NA	NA	NA	NA	NA	1,000
	0.5	11/94	NA	NA	NA	NA	NA	NA	NA	NA	970
	0.5	12/94	430	470	1,500	860	2,300	2,400	1,500	890	NA
Ammonia Nitrogen (mg/L)	0.005	10/94	NA	NA	NA	NA	NA	NA	NA	NA	0.19
	0.005	11/94	NA	NA	NA	NA	NA	NA	NA	NA	NA
	0.005	12/94	NA	NA	0.24	0.078	0.27	0.64	NA	NA	NA
Nitrate + Nitrite Nitrogen (mg/L)	0.01	10/94	NA	NA	NA	NA	NA	NA	NA	NA	ND
	0.01	11/94	NA	NA	NA	NA	NA	NA	NA	NA	NA
	0.01	12/94	NA	NA	ND	0.097	ND	ND	NA	NA	NA
Nitrite Nitrogen (mg/L)	0.001	10/94	NA	NA	NA	NA	NA	NA	NA	NA	0.039
	0.001	11/94	NA	NA	NA	NA	NA	NA	NA	NA	NA
	0.001	12/94	NA	NA	0.002	0.009	0.004	0.004	NA	NA	NA

Table F-1
General Parameters – Groundwater
Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

			Sample I.D.								
Parameter	Detection Limit	Date Sampled	G-8D1	G-8D2	G-9S	G-9D	G-10S	G-10D	G-11S	G-12	G-12D
Sulfate (mg/L)	10	10/94	NA	NA	NA	NA	NA	NA	NA	NA	230
	10	11/94	NA	NA	NA	NA	NA	NA	NA	NA	190
	10	12/94	60	60	310	180	360	370	170	210	NA
Total Coliforms (cfu/100 ml)	1	10/94	NA	NA	NA	NA	NA	NA	NA	NA	ND
	1	11/94	NA	NA	NA	NA	NA	NA	NA	NA	NA
	1	12/94	NA	NA	<2	<2	ND	ND	NA	NA	NA
Turbidity (NTU)	10	10/94	NA	NA	NA	NA	NA	NA	NA	NA	NA
	10	11/94	NA	NA	NA	NA	NA	NA	NA	NA	NA
	10	12/94	NA	NA	NA	NA	NA	NA	NA	36	NA

Notes:

ND – Not detected.
mg/L – Milligrams per liter.
µmhos/cm – Micromhos per centimeter.

Table F–1
General Parameters – Groundwater

Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Parameter	Detection Limit	Date Sampled	Sample I.D.		
			G13D	G–14D	G–15S
pH		10/94	NA	NA	7.7
		11/94	NA	NA	8.4
		12/94	9.2	9.4	8.4
Total Organic Cargon (mg/L)	1.0	10/94	NA	NA	ND
	1.0	11/94	NA	NA	NA
	1.0	12/94	ND	ND	NA
Chemical Oxygen Demand (mg/L)	10	10/94	NA	NA	19
	10	11/94	NA	NA	NA
	10	12/94	11	19	NA
Chloride (mg/L)	1.0	10/94	NA	NA	2.2
	1.0	11/94	NA	NA	2.3
	1.0	12/94	3.8	2.2	2.1
Conductivity (µmhos/cm)	0.5	10/94	NA	NA	950
	0.5	11/94	NA	NA	390
	0.5	12/94	510	400	400
Ammonia Nitrogen (mg/L)	0.005	10/94	NA	NA	0.020
	0.005	11/94	NA	NA	NA
	0.005	12/94	0.14	0.15	NA
Nitrate + Nitrite Nitrogen (mg/L)	0.01	10/94	NA	NA	ND
	0.01	11/94	NA	NA	NA
	0.01	12/94	ND	0.020	NA
Nitrite Nitrogen (mg/L)	0.001	10/94	NA	NA	0.005
	0.001	11/94	NA	NA	NA
	0.001	12/94	0.005	0.007	NA

Table F−1
General Parameters − Groundwater
Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Parameter	Detection Limit	Date Sampled	Sample I.D.		
			G13D	G−14D	G−15S
Sulfate (mg/L)	10	10/94	NA	NA	39
	10	11/94	NA	NA	38
	10	12/94	95	16	59
Total Coliforms (cfu/100 ml)	1	10/94	NA	NA	ND
	1	11/94	NA	NA	NA
	1	12/94	<2	<2	NA
Turbidity (NTU)	10	10/94	NA	NA	NA
	10	11/94	NA	NA	NA
	10	12/94	NA	NA	5.5

Notes:

ND − Not detected.
mg/L − Milligrams per liter.
µmhos/cm − Micromhos per centimeter.

Table F–2
Dissolved Metals – Groundwater
Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Metal	Detection Limit (mg/L)	Date Sampled	Sample I.D.										
			G–1D	G–2D	G–4A	G–6B	G–7S	G–7D	G–9S	G–9D	G–10S	G–10D	G–12D
			mg/L										
Arsenic	0.001	10/94	NA	NA	0.001	0.001	0.003	0.004	NA	NA	NA	NA	0.001
	0.001	11/94	0.001	0.008	NA	NA	NA	NA	NA	NA	NA	NA	NA
	0.001	12/94	NA	NA	NA	NA	NA	NA	0.001	0.007	ND	0.001	NA
Barium	0.003	10/94	NA	NA	0.004	ND	0.004	ND	NA	NA	NA	NA	ND
	0.003	11/94	ND	ND	NA	NA	NA	NA	NA	NA	NA	NA	NA
	0.003	12/94	NA	NA	NA	NA	NA	NA	0.005	ND	0.007	ND	NA
Cadmium	0.002	10/94	NA	NA	ND	ND	ND	ND	NA	NA	NA	NA	0.003
	0.002	11/94	ND	ND	NA	NA	NA	NA	NA	NA	NA	NA	NA
	0.002	12/94	NA	NA	NA	NA	NA	NA	0.002	ND	ND	ND	NA
Chromium	0.006	10/94	NA	NA	ND	ND	ND	ND	NA	NA	NA	NA	ND
	0.006	11/94	ND	ND	NA	NA	NA	NA	NA	NA	NA	NA	NA
	0.006	12/94	NA	NA	NA	NA	NA	NA	ND	ND	ND	ND	NA
Copper	0.002	10/94	NA	NA	ND	ND	ND	ND	NA	NA	NA	NA	0.002
	0.002	11/94	ND	ND	NA	NA	NA	NA	NA	NA	NA	NA	NA
	0.002	12/94	NA	NA	NA	NA	NA	NA	ND	0.004	ND	ND	NA
Iron	0.01	10/94	NA	NA	7.6	0.07	0.03	0.08	NA	NA	NA	NA	0.04
	0.01	11/94	0.09	0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA
	0.01	12/94	NA	NA	NA	NA	NA	NA	0.01	0.13	0.03	0.02	NA
Mercury	0.0002	10/94	NA	NA	ND	ND	ND	ND	NA	NA	NA	NA	ND
	0.0002	11/94	ND	ND	NA	NA	NA	NA	NA	NA	NA	NA	NA
	0.0002	12/94	NA	NA	NA	NA	NA	NA	ND	0.0002	ND	ND	NA
Manganese	0.002	10/94	NA	NA	6.3	ND	1.7	0.003	NA	NA	NA	NA	0.002
	0.002	11/94	0.007	ND	NA	NA	NA	NA	NA	NA	NA	NA	NA
	0.002	12/94	NA	NA	NA	NA	NA	NA	1.0	0.018	7.3	1.4	NA
Nickel	0.01	10/94	NA	NA	ND	ND	ND	ND	NA	NA	NA	NA	ND
	0.01	11/94	ND	ND	NA	NA	NA	NA	NA	NA	NA	NA	NA
	0.01	12/94	NA	NA	NA	NA	NA	NA	0.04	ND	0.02	ND	NA
Lead	0.001	10/94	NA	NA	ND	ND	ND	ND	NA	NA	NA	NA	ND
	0.001	11/94	ND	ND	NA	NA	NA	NA	NA	NA	NA	NA	NA
	0.001	12/94	NA	NA	NA	NA	NA	NA	ND	ND	ND	ND	NA

Table F–2
Dissolved Metals – Groundwater
Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Metal	Detection Limit (mg/L)	Date Sampled	Sample I.D. G–1D	G–2D	G–4A	G–6B	G–7S	G–7D	G–9S	G–9D	G–10S	G–10D	G–12D
			mg/L										
Selenium	0.001	10/94	NA	NA	ND	ND	ND	ND	NA	NA	NA	NA	ND
	0.001	11/94	ND	ND	NA	NA	NA	NA	NA	NA	NA	NA	NA
	0.001	12/94	NA	NA	NA	NA	NA	NA	ND	0.001	ND	ND	NA
Silver	0.01	10/94	NA	NA	ND	ND	ND	ND	NA	NA	NA	NA	ND
	0.01	11/94	ND	ND	NA	NA	NA	NA	NA	NA	NA	NA	NA
	0.01	12/94	NA	NA	NA	NA	NA	NA	ND	ND	ND	ND	NA
Zinc	0.002	10/94	NA	NA	ND	0.003	ND	ND	NA	NA	NA	NA	0.005
	0.002	11/94	ND	ND	NA	NA	NA	NA	NA	NA	NA	NA	NA
	0.002	12/94	NA	NA	NA	NA	NA	NA	0.008	0.006	0.005	ND	NA

Notes:

mg/L – Milligrams per liter.
NA – Not analyzed.
ND – Not detected.

Table F–2
Dissolved Metals – Groundwater

Snohomish Co. Public Works Dept./Cath
Snohomish County, Washington

Metal	Detection Limit (mg/L)	Date Sampled	Sample I.D.			
			G–13D	G–14D	G–14D	G–15S
			mg/L			
Arsenic	0.001	10/94	0.001	NA	NA	0.001
	0.001	11/94	NA	NA	NA	NA
	0.001	12/94	0.001	0.002	NA	NA
Barium	0.003	10/94	NA	NA	NA	ND
	0.003	11/94	NA	NA	NA	NA
	0.003	12/94	ND	0.003	NA	NA
Cadmium	0.002	10/94	NA	NA	NA	ND
	0.002	11/94	NA	NA	NA	NA
	0.002	12/94	ND	ND	NA	NA
Chromium	0.006	10/94	NA	NA	NA	ND
	0.006	11/94	NA	NA	NA	NA
	0.006	12/94	ND	ND	NA	NA
Copper	0.002	10/94	NA	NA	NA	0.003
	0.002	11/94	NA	NA	NA	NA
	0.002	12/94	0.002	0.003	NA	NA
Iron	0.01	10/94	NA	NA	NA	0.05
	0.01	11/94	NA	NA	NA	NA
	0.01	12/94	0.78	0.57	NA	NA
Mercury	0.0002	10/94	NA	NA	NA	ND
	0.0002	11/94	NA	NA	NA	NA
	0.0002	12/94	0.0003	0.0004	NA	NA
Manganese	0.002	10/94	NA	NA	NA	0.009
	0.002	11/94	NA	NA	NA	NA
	0.002	12/94	0.020	0.008	NA	NA
Nickel	0.01	10/94	NA	NA	NA	ND
	0.01	11/94	NA	NA	NA	NA
	0.01	12/94	ND	ND	NA	NA
Lead	0.001	10/94	NA	NA	NA	ND
	0.001	11/94	NA	NA	NA	NA
	0.001	12/94	0.001	ND	NA	NA

Table F–2
Dissolved Metals – Groundwater
Snohomish Co. Public Works Dept./Cath
Snohomish County, Washington

			Sample I.D.			
	Detection Limit	Date	G–13D	G–14D	G–14D	G–15S
Metal	(mg/L)	Sampled	mg/L			
Selenium	0.001	10/94	NA	NA	NA	0.001
	0.001	11/94	NA	NA	NA	NA
	0.001	12/94	ND	ND	NA	NA
Silver	0.01	10/94	NA	NA	NA	ND
	0.01	11/94	NA	NA	NA	NA
	0.01	12/94	ND	ND	NA	NA
Zinc	0.002	10/94	NA	NA	NA	0.003
	0.002	11/94	NA	NA	NA	NA
	0.002	12/94	ND	ND	NA	NA

Notes:

mg/L – Milligrams per liter.
NA – Not analyzed.
ND – Not detected.

Table F–3
Volatile Organic Compounds – Groundwater
Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Compound	Detection Limit (µg/L)	Date Sampled	Sample I.D.							
			G–1D	G–2D	G–4A	G–6B	8 G–7S	9 G–7D	G–9S	G–9D
			µg/L							
Chloromethane	5.0	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	5.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	5.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND
Vinyl Chloride	5.0	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	5.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	5.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND
Bromomethane	5.0	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	5.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	5.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND
Chloroethane	5.0	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	5.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	5.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND
Trichlorofluoromethane	1.0	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	1.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	1.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND
1,1–Dichloroethylene	1.0	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	1.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	1.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND
Acetone	20	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	20	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	20	12/94	NA	NA	NA	NA	NA	NA	ND	ND
Carbon Disulfide	1.0	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	1.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	1.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND
Methylene Chloride	1.0	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	1.0	11/94	1.0 B	1.1 B	NA	NA	NA	NA	NA	NA
	1.0	12/94	NA	NA	NA	NA	NA	NA	1.2 B	1.4 B
1,2–Dichloroethylene	1.0	10/94	NA	NA	4.2	ND	ND	ND	NA	NA
	1.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	1.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND

Table F–3
Volatile Organic Compounds – Groundwater

Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Compound	Detection Limit (µg/L)	Date Sampled	G–1D	G–2D	G–4A	G–6B	8 G–7S	9 G–7D	G–9S	G–9D
			µg/L							
1,1–Dichloroethane	1.0	10/94	NA	NA	1.8	ND	ND	ND	NA	NA
	1.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	1.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND
Vinyl Acetate	10	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	10	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	10	12/94	NA	NA	NA	NA	NA	NA	ND	ND
2–Butanone (MEK)	10	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	10	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	10	12/94	NA	NA	NA	NA	NA	NA	ND	ND
Chloroform	1.0	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	1.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	1.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND
1,1,1–Trichloroethane	1.0	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	1.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	1.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND
Carbon Tetrachloride	1.0	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	1.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	1.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND
Benzene	1.0	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	1.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	1.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND
1,2–Dichloroethane	1.0	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	1.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	1.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND
1,1,2–Trichloroethene	1.0	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	1.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	1.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND
Bromodichloromethane	1.0	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	1.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	1.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND

Table F–3
Volatile Organic Compounds – Groundwater
Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Compound	Detection Limit (µg/L)	Date Sampled	Sample I.D. G–1D	G–2D	G–4A	G–6B	8 G–7S	9 G–7D	G–9S	G–9D
			µg/L							
1,2–Dichloropropane	1.0	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	1.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	1.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND
4–Methyl–2–Pentanone	10	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	10	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	10	12/94	NA	NA	NA	NA	NA	NA	ND	ND
Toluene	1.0	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	1.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	1.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND
cis–1,3–Dichloropropene	1.0	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	1.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	1.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND
1,1,2–Trichloroethane	1.0	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	1.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	1.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND
Tetrachloroethylene	1.0	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	1.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	1.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND
2–Hexanone	10	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	10	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	10	12/94	NA	NA	NA	NA	NA	NA	ND	ND
Chlorodibromomethane	1.0	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	1.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	1.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND
Chlorobenzene	1.0	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	1.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	1.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND
Ethylbenzene	1.0	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	1.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	1.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND

Table F–3
Volatile Organic Compounds – Groundwater
Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Compound	Detection Limit (µg/L)	Date Sampled	Sample I.D.							
			G–1D	G–2D	G–4A	G–6B	8 G–7S	9 G–7D	G–9S	G–9D
			µg/L							
Total Xylenes	1.0	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	1.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	1.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND
Styrene	1.0	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	1.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	1.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND
Bromoform	1.0	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	1.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	1.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND
1,1,2,2–Tetrachloroethane	1.0	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	1.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	1.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND
trans–1,3–Dichloropropene	1.0	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	1.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	1.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND
p–Dichlorobenzene	1.0	10/94	NA	NA	ND	ND	ND	ND	NA	NA
	1.0	11/94	ND	ND	NA	NA	NA	NA	NA	NA
	1.0	12/94	NA	NA	NA	NA	NA	NA	ND	ND

Table F–3
Volatile Organic Compounds – Groundwater
Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Compound	Detection Limit (µg/L)	Date Sampled	Sample I.D.							
			G–10S	G–10D	G–12	G–12D	G–13D	G–14D	G–14D	G–15S
			µg/L							
Chloromethane	5.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	5.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	5.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA
Vinyl Chloride	5.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	5.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	5.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA
Bromomethane	5.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	5.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	5.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA
Chloroethane	5.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	5.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	5.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA
Trichlorofluoromethane	1.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	1.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	1.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA
1,1–Dichloroethylene	1.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	1.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	1.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA
Acetone	20	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	20	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	20	12/94	ND	ND	NA	NA	ND	ND	ND	NA
Carbon Disulfide	1.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	1.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	1.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA
Methylene Chloride	1.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	1.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	1.0	12/94	1.9 B	2.5 B	NA	NA	1.4 B	ND	1.0 B	NA
1,2–Dichloroethylene	1.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	1.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	1.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA

Table F–3
Volatile Organic Compounds – Groundwater
Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

	Detection		Sample I.D.							
	Limit	Date	G–10S	G–10D	G–12	G–12D	G–13D	G–14D	G–14D	G–15S
Compound	(µg/L)	Sampled	µg/L							
1,1–Dichloroethane	1.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	1.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	1.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA
Vinyl Acetate	10	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	10	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	10	12/94	ND	ND	NA	NA	ND	ND	ND	NA
2–Butanone (MEK)	10	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	10	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	10	12/94	ND	ND	NA	NA	ND	ND	ND	NA
Chloroform	1.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	1.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	1.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA
1,1,1–Trichloroethane	1.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	1.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	1.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA
Carbon Tetrachloride	1.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	1.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	1.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA
Benzene	1.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	1.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	1.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA
1,2–Dichloroethane	1.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	1.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	1.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA
1,1,2–Trichloroethene	1.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	1.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	1.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA
Bromodichloromethane	1.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	1.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	1.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA

Table F–3
Volatile Organic Compounds – Groundwater
Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

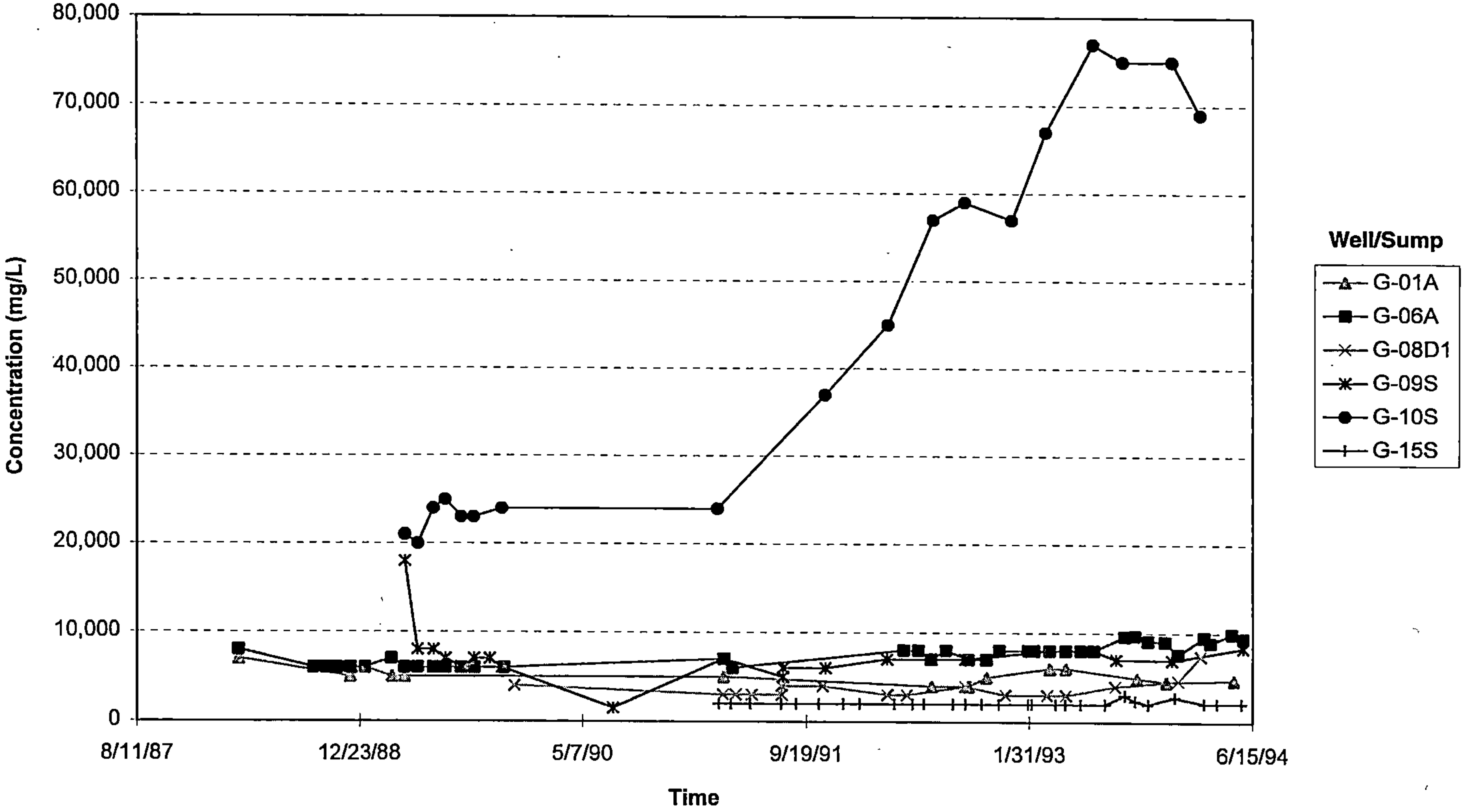
Compound	Detection Limit (µg/L)	Date Sampled	Sample I.D.							
			G–10S	G–10D	G–12	G–12D	G–13D	G–14D	G–14D	G–15S
			µg/L							
1,2–Dichloropropane	1.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	1.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	1.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA
4–Methyl–2–Pentanone	10	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	10	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	10	12/94	ND	ND	NA	NA	ND	ND	ND	NA
Toluene	1.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	1.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	1.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA
cis–1,3–Dichloropropene	1.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	1.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	1.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA
1,1,2–Trichloroethane	1.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	1.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	1.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA
Tetrachloroethylene	1.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	1.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	1.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA
2–Hexanone	10	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	10	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	10	12/94	ND	ND	NA	NA	ND	ND	ND	NA
Chlorodibromomethane	1.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	1.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	1.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA
Chlorobenzene	1.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	1.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	1.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA
Ethylbenzene	1.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	1.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	1.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA

Table F–3
Volatile Organic Compounds – Groundwater
Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Compound	Detection Limit (µg/L)	Date Sampled	Sample I.D.							
			G–10S	G–10D	G–12	G–12D	G–13D	G–14D	G–14D	G–15S
			µg/L							
Total Xylenes	1.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	1.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	1.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA
Styrene	1.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	1.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	1.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA
Bromoform	1.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	1.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	1.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA
1,1,2,2–Tetrachloroethane	1.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	1.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	1.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA
trans–1,3–Dichloropropene	1.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	1.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	1.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA
p–Dichlorobenzene	1.0	10/94	NA	NA	NA	ND	NA	NA	NA	ND
	1.0	11/94	NA	NA	NA	NA	NA	NA	NA	NA
	1.0	12/94	ND	ND	NA	NA	ND	ND	ND	NA

Notes:

B – Compound detected in method blank; possible laboratory contaminant.
ND – Not detected.



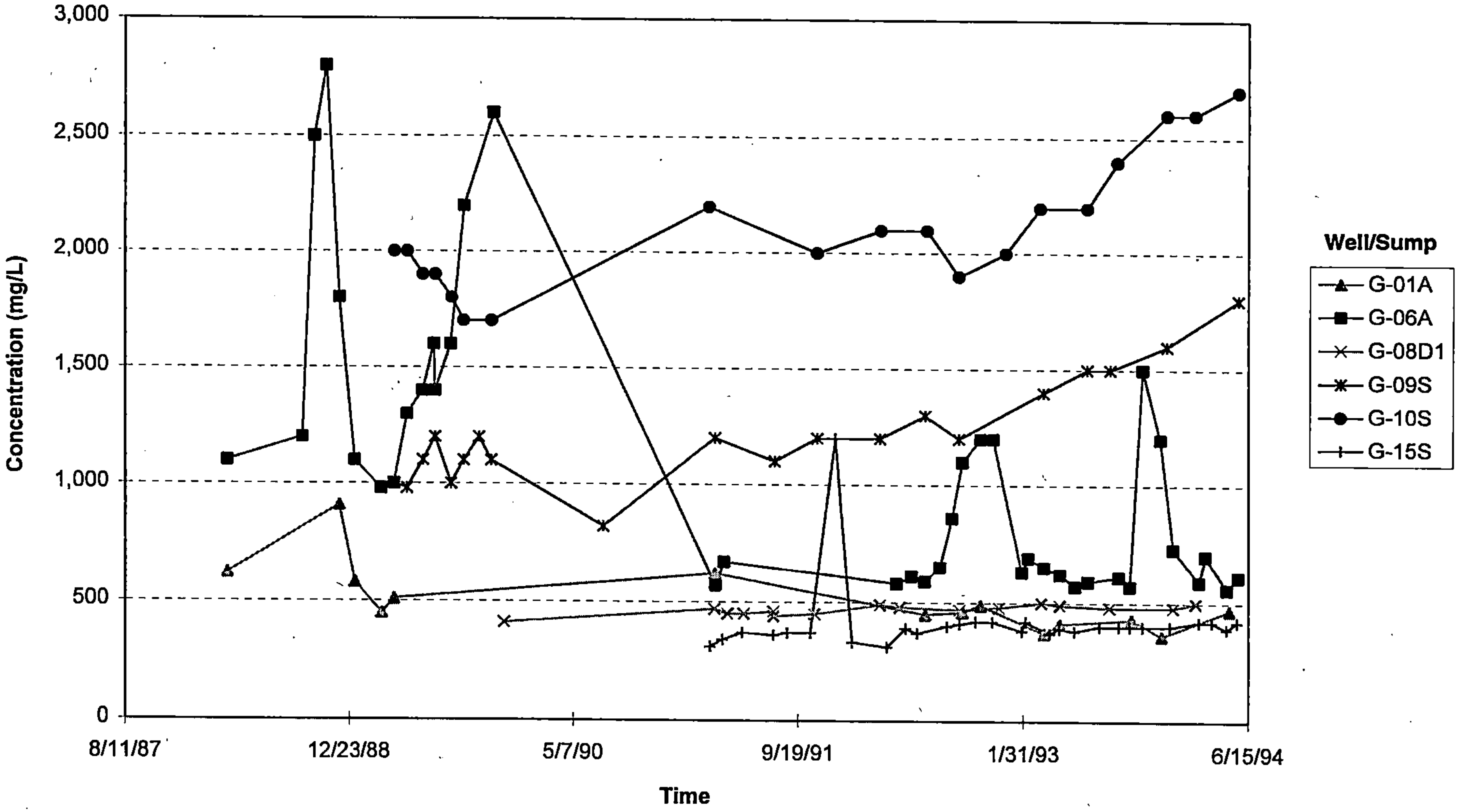
AGI
TECHNOLOGIES

Chemistry Trends: Chloride - Shallow Groundwater Zone

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PLATE
F-1

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95	TMM		



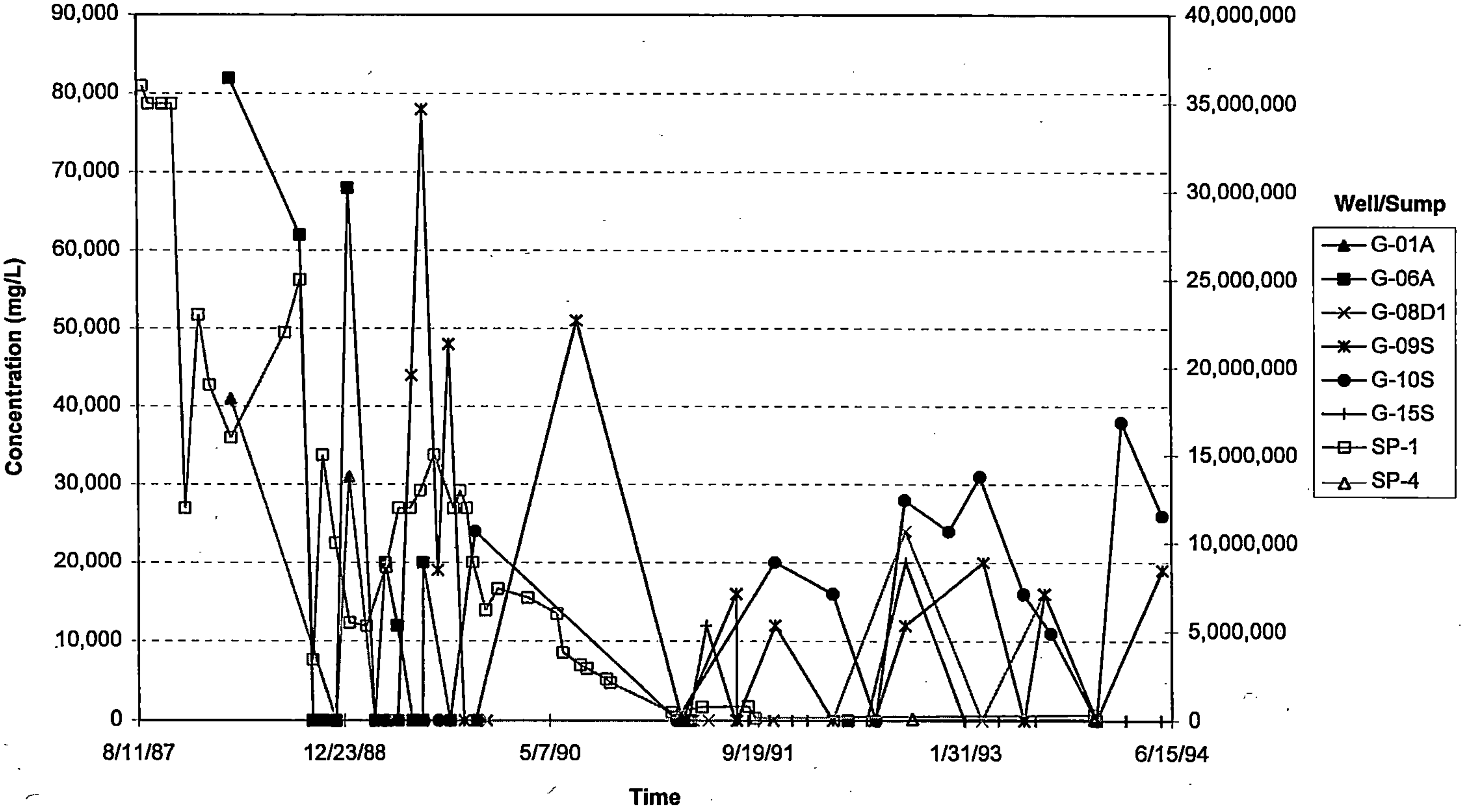
AGI
TECHNOLOGIES

Chemistry Trends: Conductivity - Shallow Groundwater Zone

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PLATE
F-2

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95	TMM		



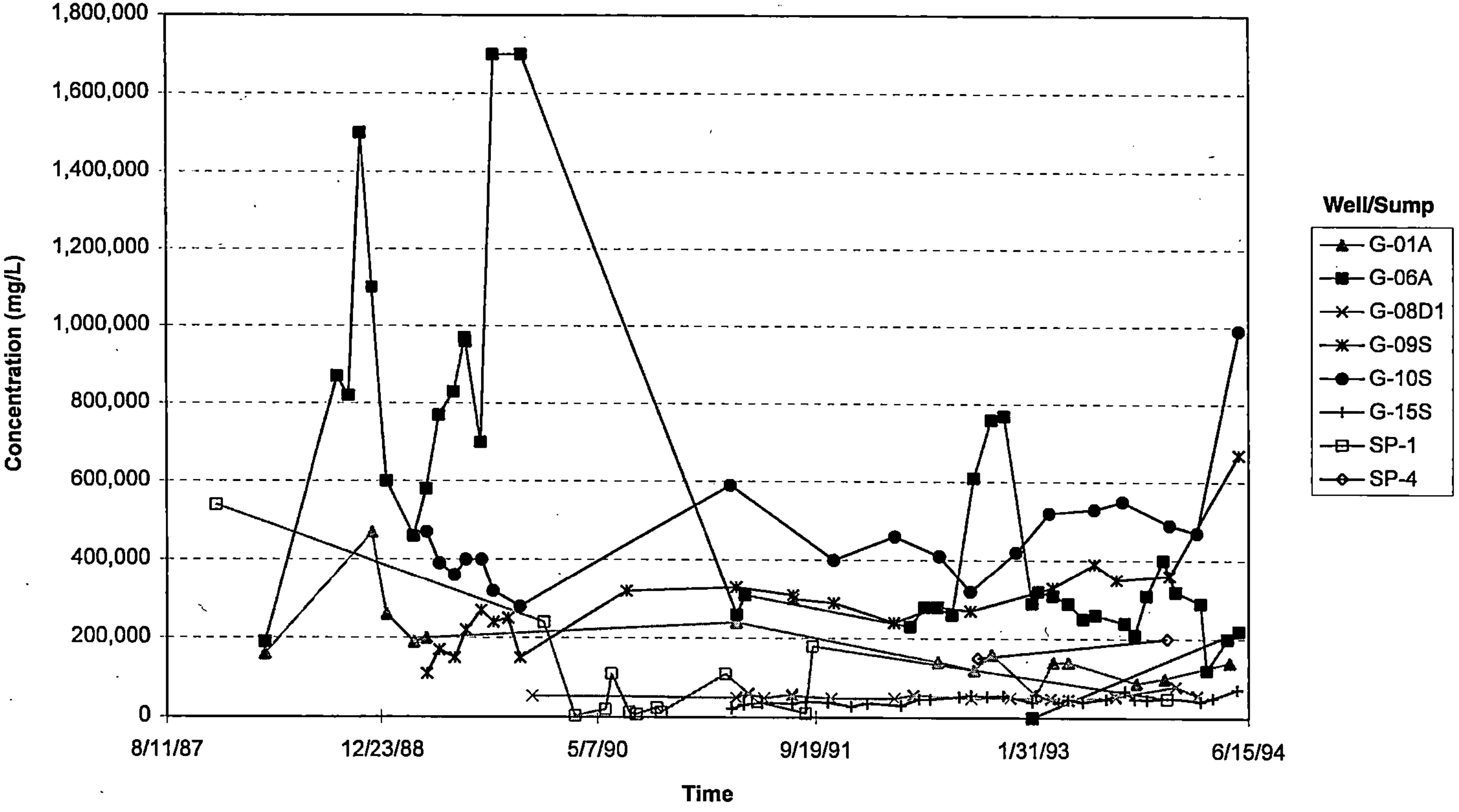
AGI
TECHNOLOGIES

Chemistry Trends: COD - Shallow Groundwater Zone

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PLATE
F-3

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95	TMM		



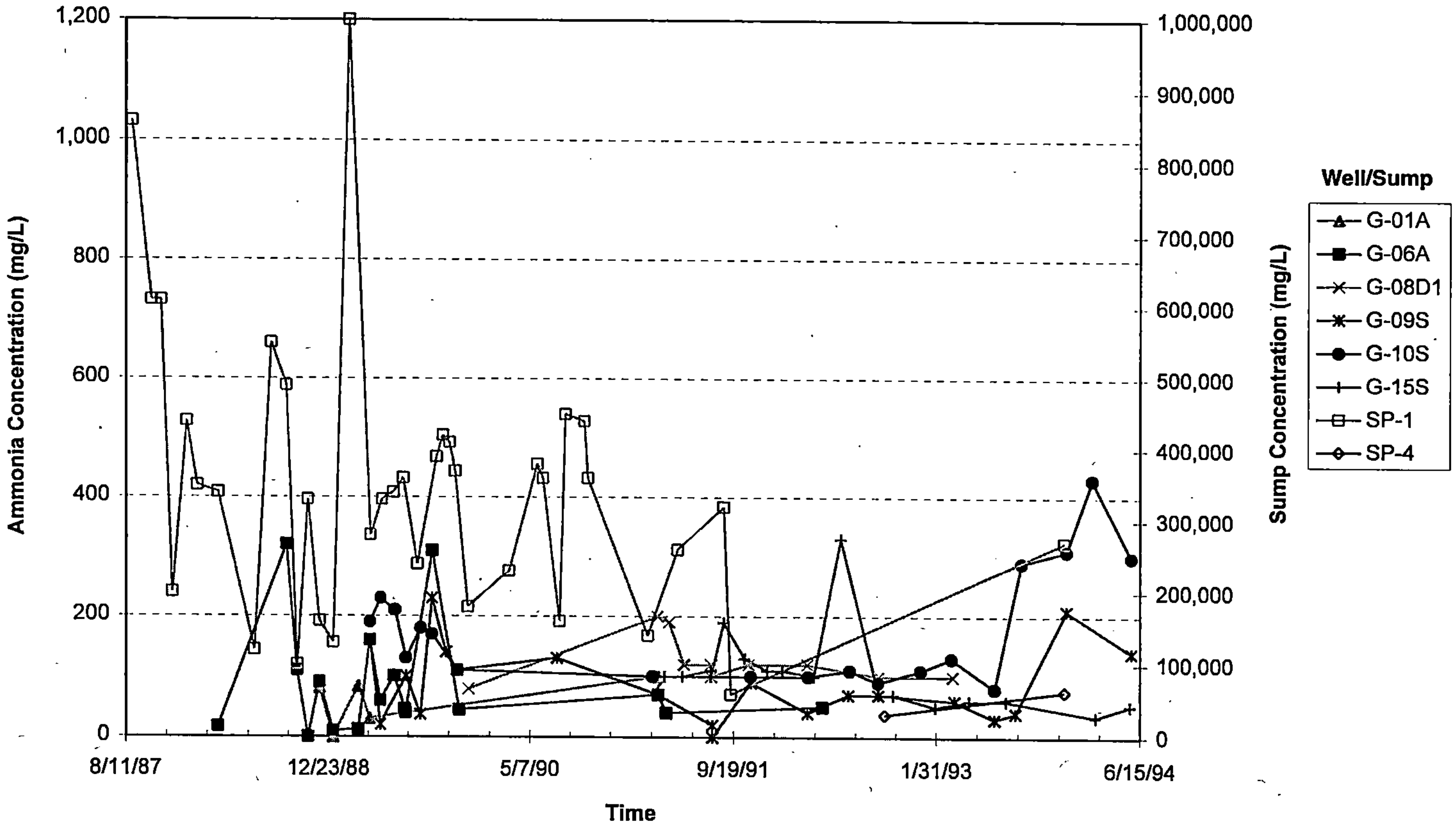
AGI
TECHNOLOGIES

Chemistry Trends: Sulfate - Shallow Groundwater Zone

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PLATE
F-4

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95	TMM		



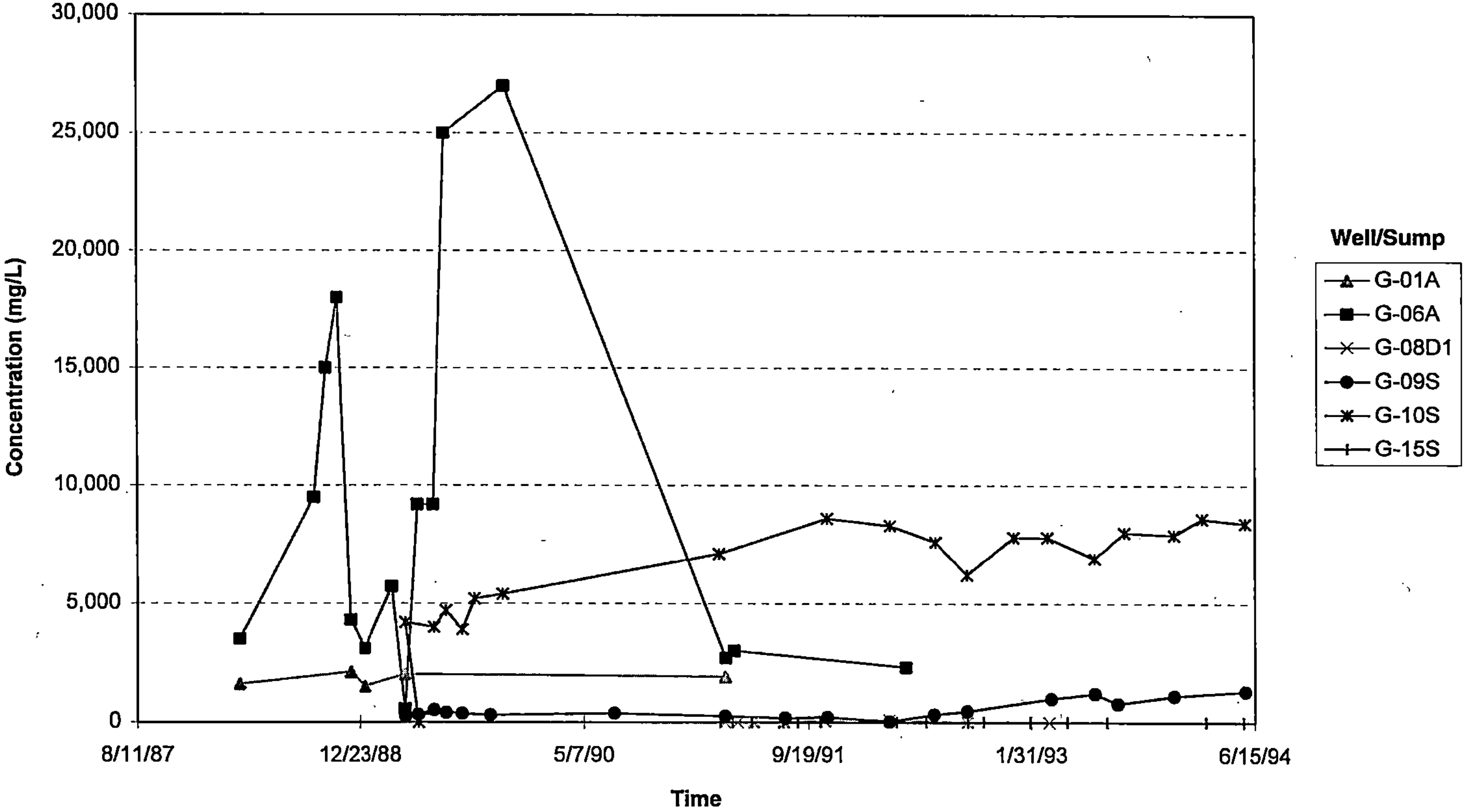
AGI
TECHNOLOGIES

Chemistry Trends: Ammonia - Shallow Groundwater Zone

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PLATE
F-5

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95	TMM		



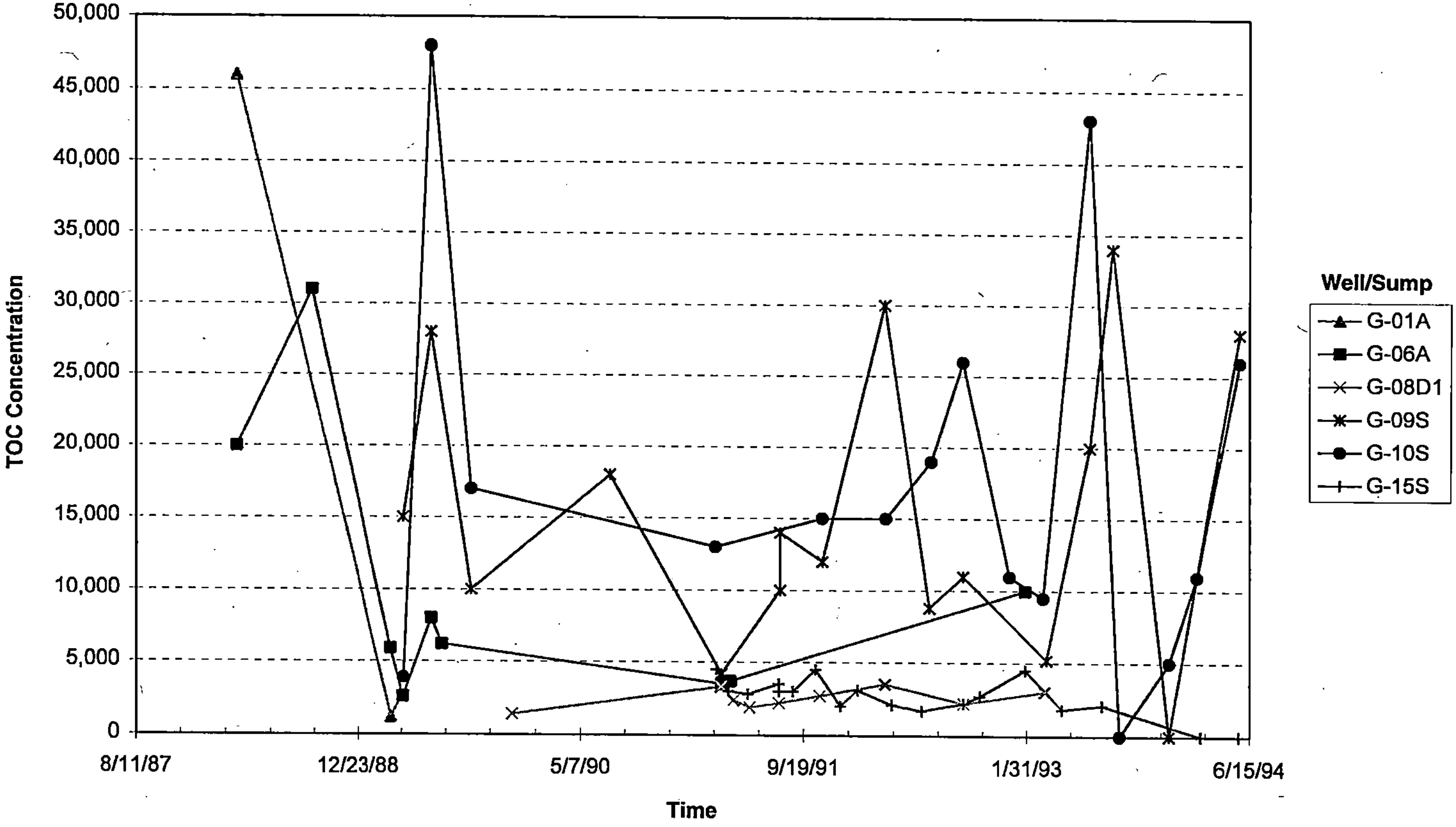
AGI TECHNOLOGIES

Chemistry Trends: Manganese - Shallow Groundwater Zone

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PLATE
F-6

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95	TMM		



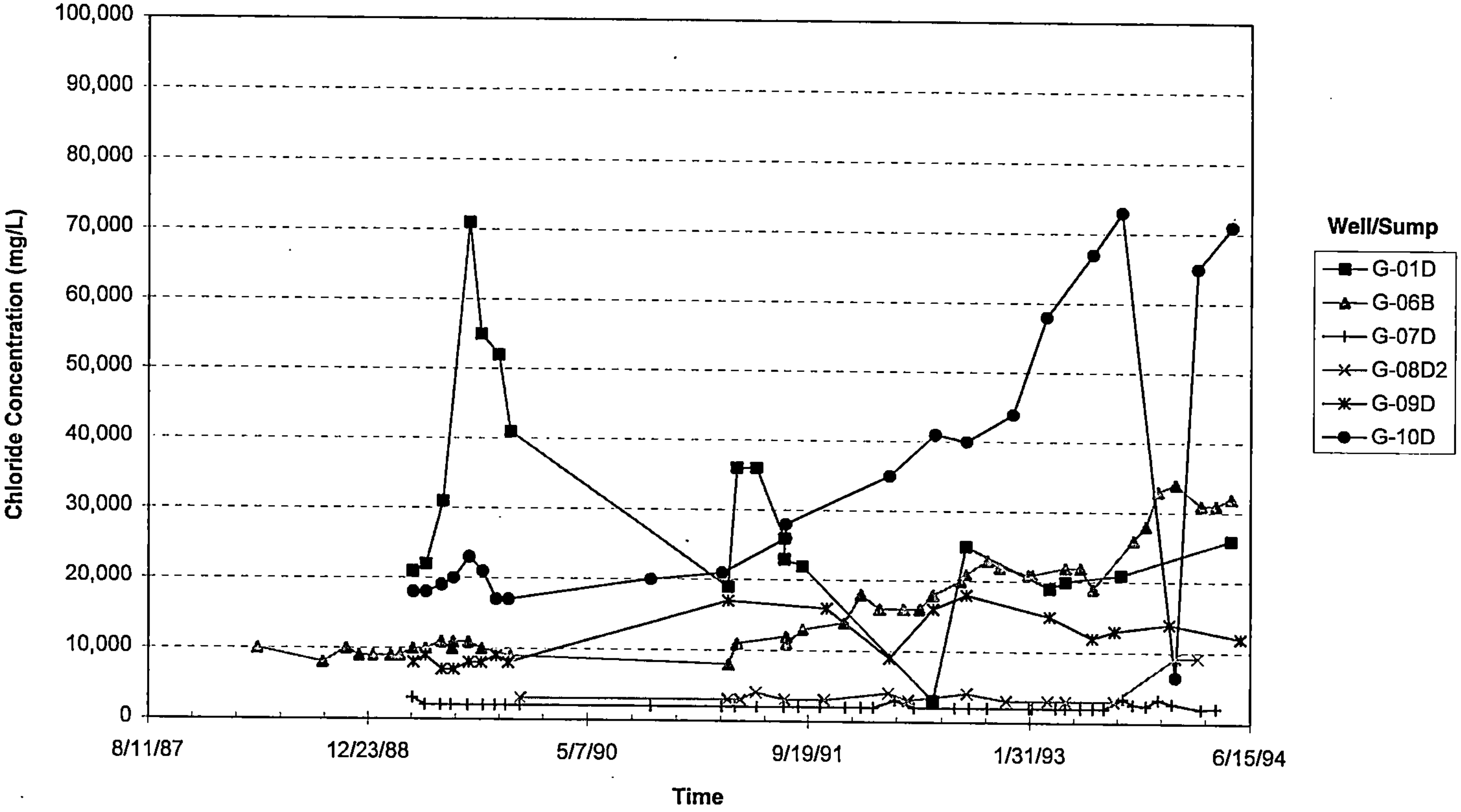
AGI
TECHNOLOGIES

Chemistry Trends: TOC - Shallow Groundwater Zone

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95			

PLATE
F-7



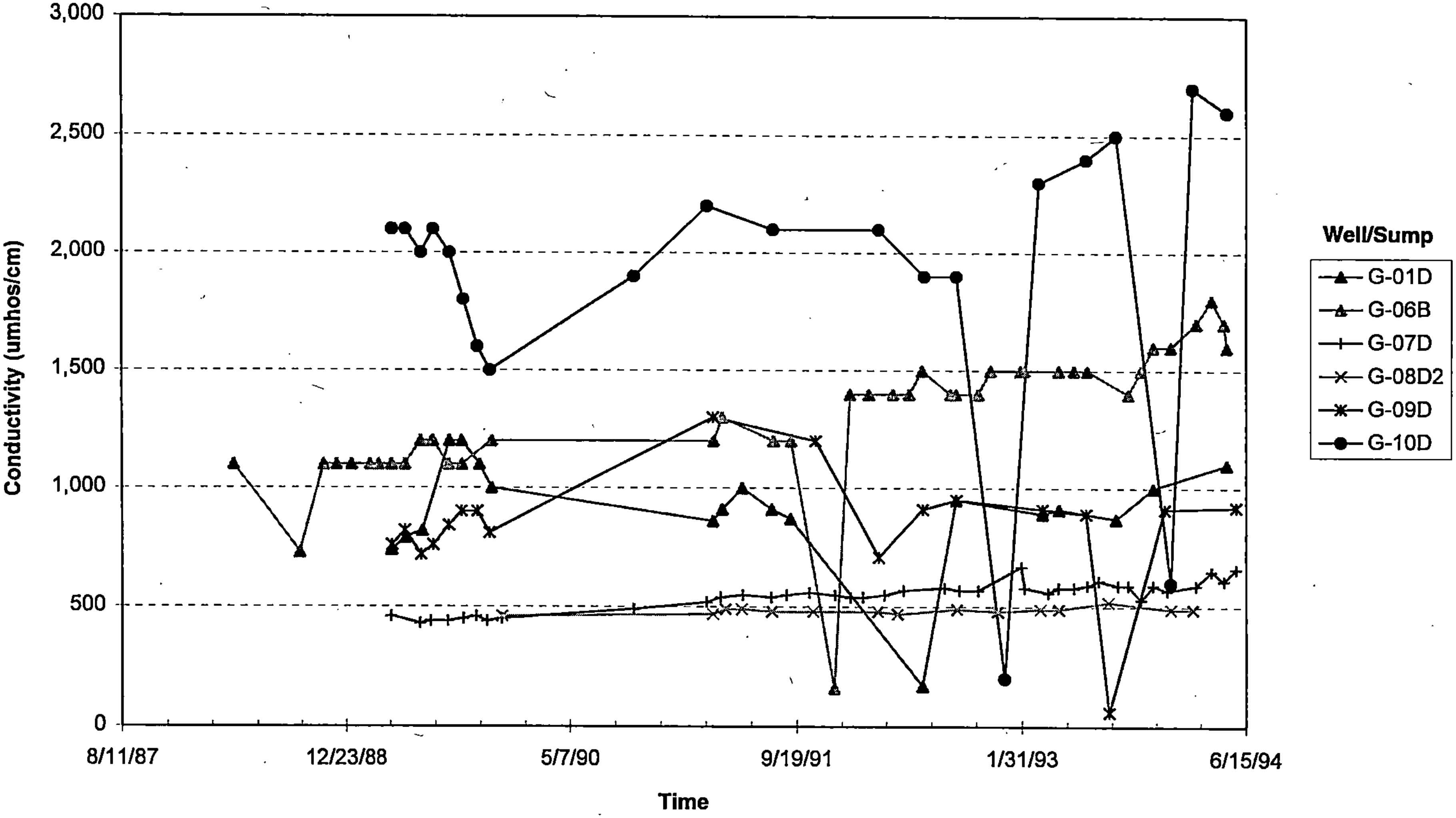
AGI
TECHNOLOGIES

Chemistry Trends: Chloride - Deep Groundwater Zone

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95			

PLATE
F-8



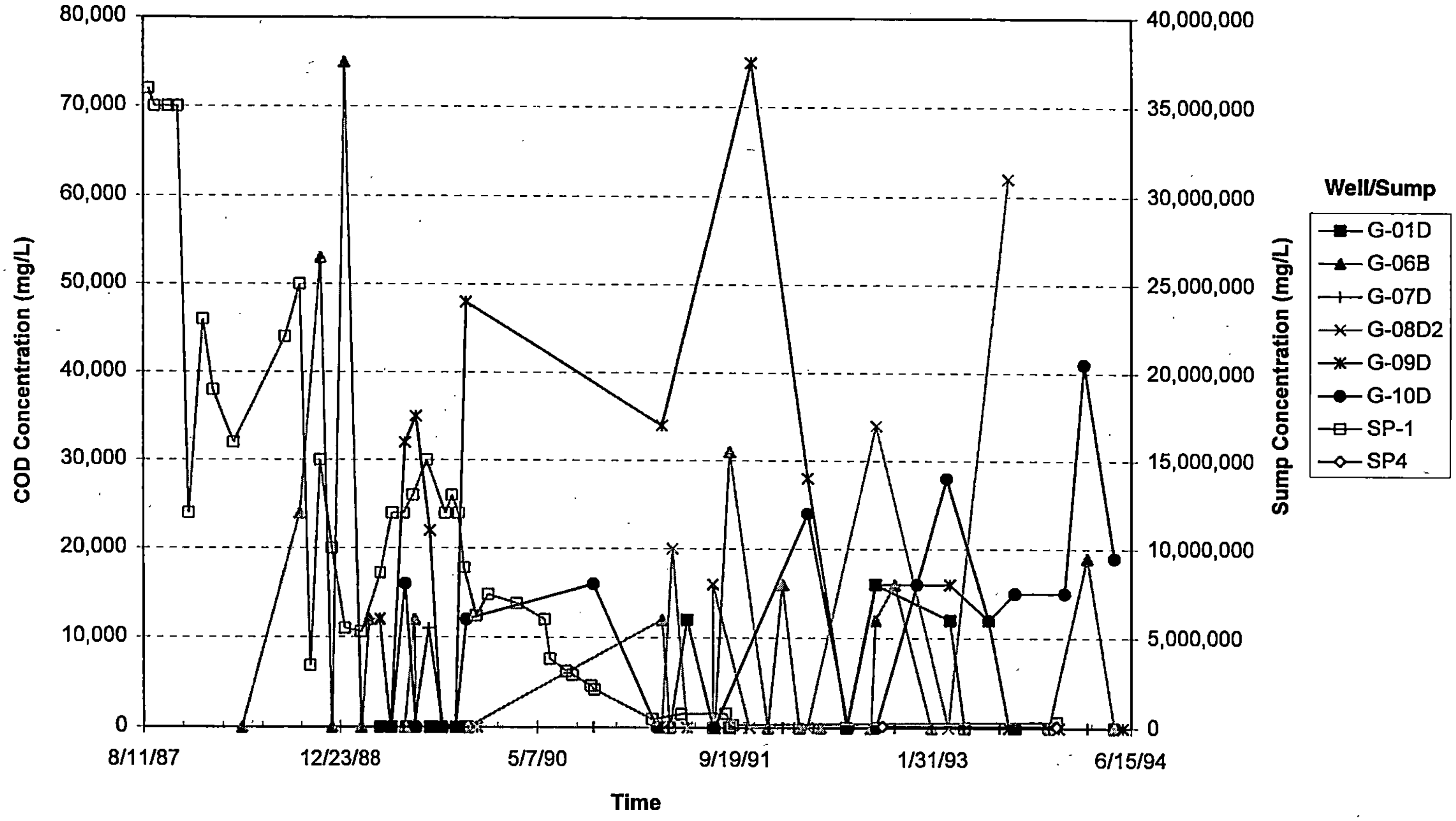
AGI TECHNOLOGIES

Chemistry Trends: Conductivity - Deep Groundwater Zone

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95	TMM		

PLATE
F-9



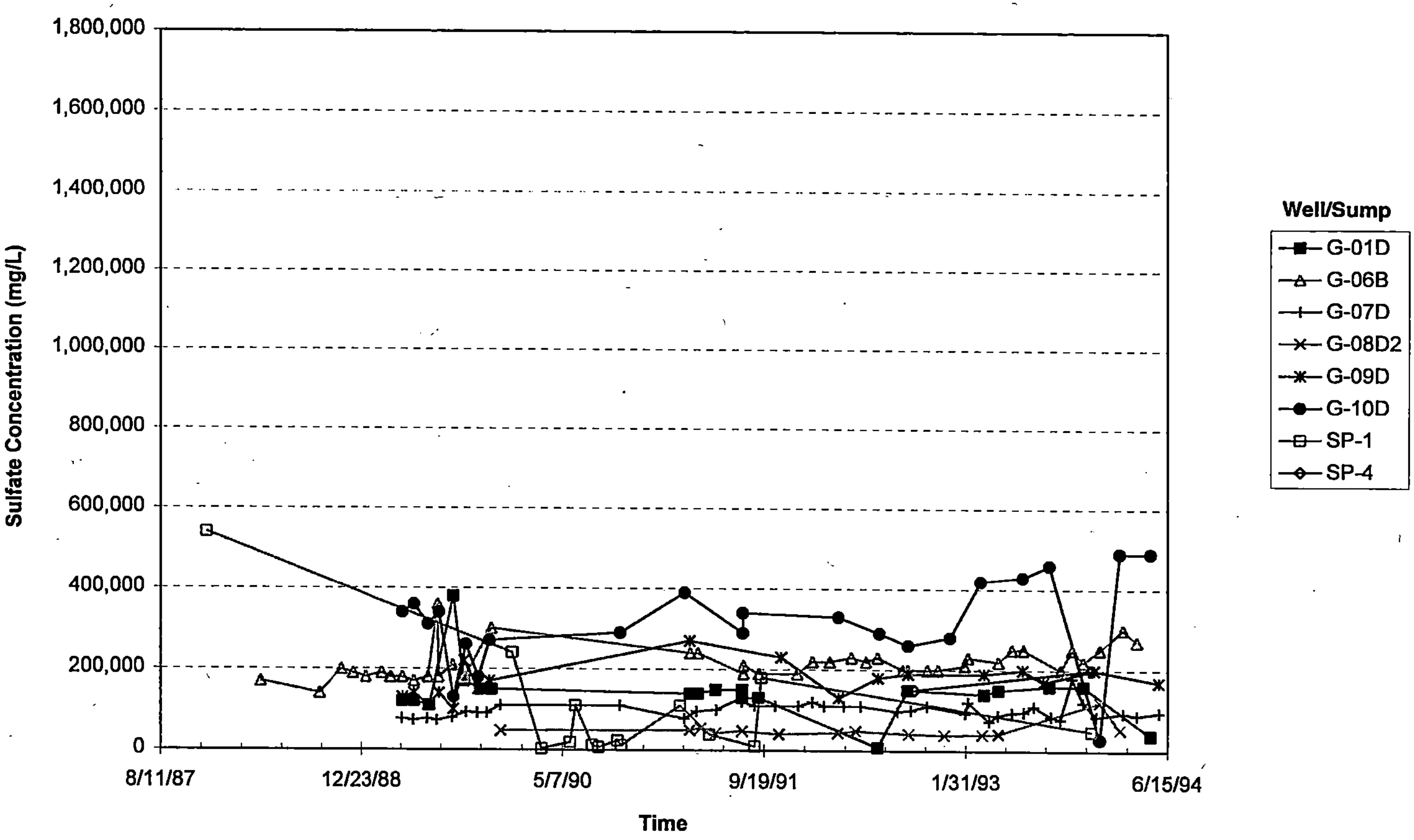
AGI
TECHNOLOGIES

Chemistry Trends: COD - Deep Groundwater Zone

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PLATE
F-10

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95	TMM		



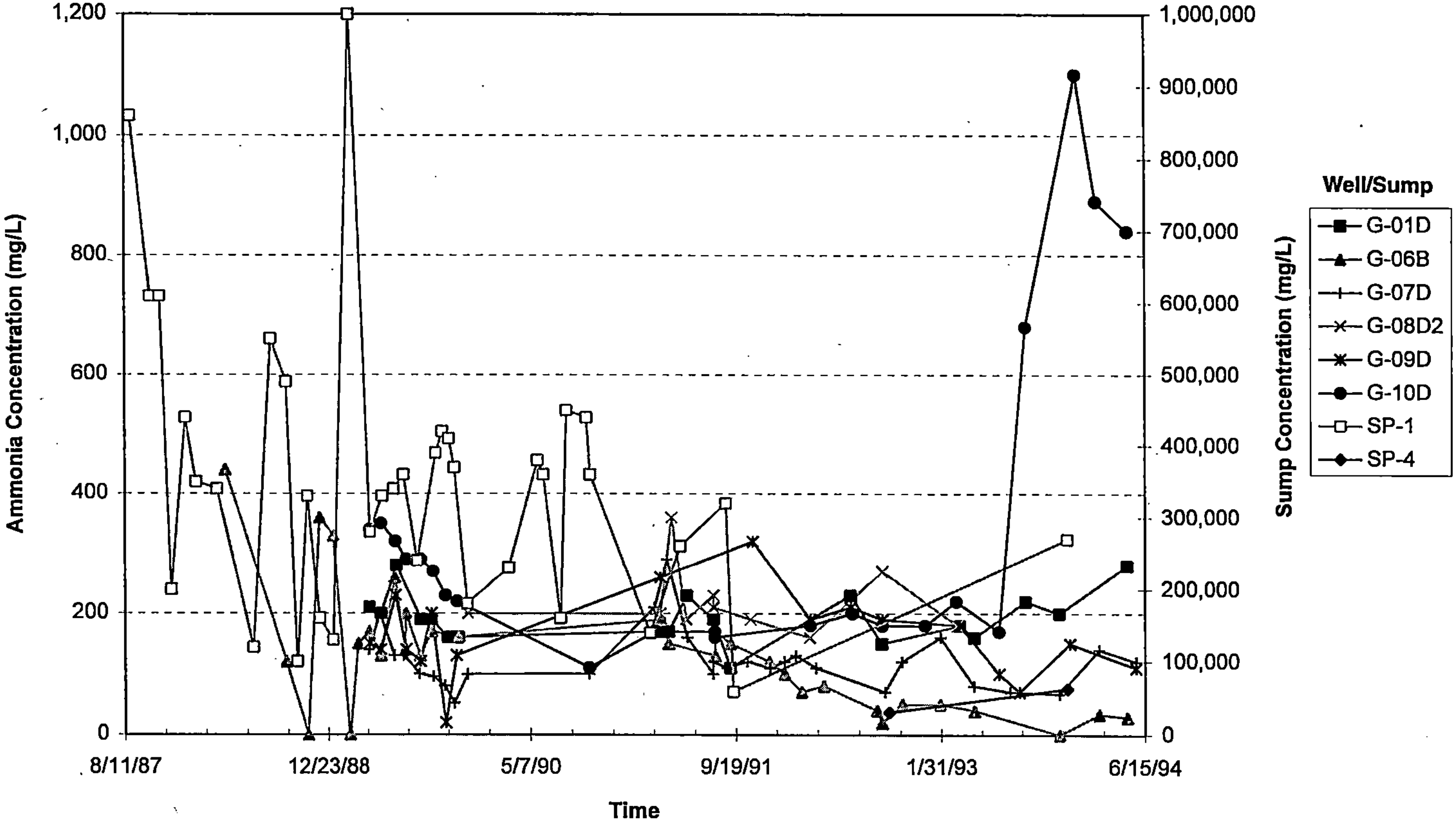
AGI
TECHNOLOGIES

Chemistry Trends: Sulfate - Deep Groundwater Zone

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PLATE
F-11

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95			



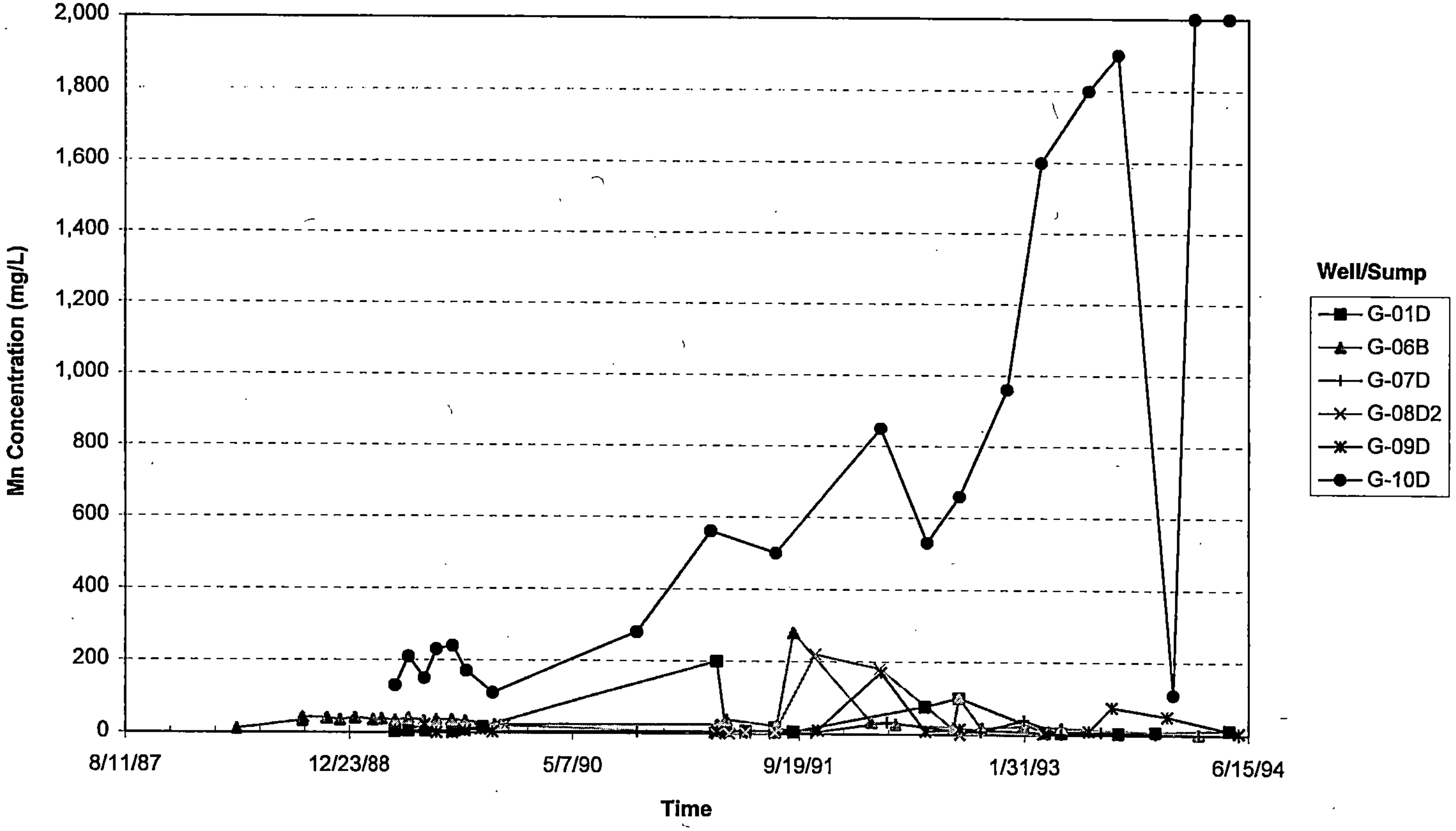
AGI
TECHNOLOGIES

Chemistry Trends: Ammonia - Deep Groundwater Zone

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95			

PLATE
F-12



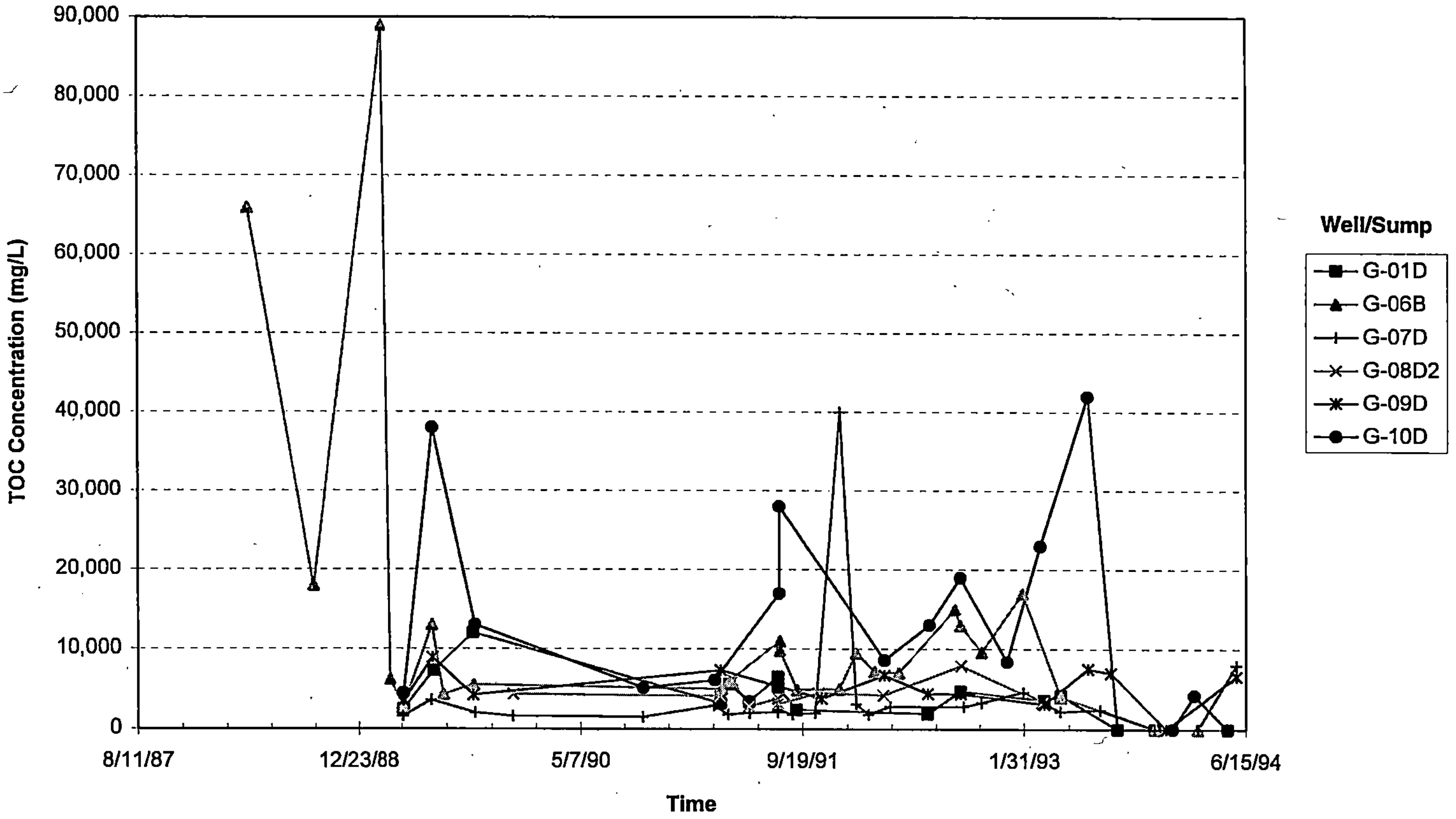
AGI
TECHNOLOGIES

Chemistry Trends: Manganese - Deep Groundwater Zone

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PLATE
F-13

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95			



AGI
TECHNOLOGIES

Chemistry Trends: TOC - Deep Groundwater Zone

Snohomish Co. Public Works Dept./Cathcart Landfill Phase II
Snohomish County, Washington

PROJECT NO.	DRAWN	DATE	APPROVED	REVISED	DATE
15,512.108	DFF	7 Mar 95	TMM		

PLATE
F-14

CHEMICAL DATA QUALITY REVIEW

Project Name: Snohomish County/Cathcart Landfill
Project No.: 15,512.108

AGI performed a general chemical data quality review of third quarter 1994 groundwater sampling results for the Cathcart Landfill. Results of associated laboratory method blanks, matrix spike/matrix spike duplicate (MS/MSD) percent recoveries and relative percent differences (RPDs), surrogate spike percent recoveries, accompanying chromatography, methods of analysis, and holding time requirements were evaluated. Findings are summarized below.

The laboratory reports reviewed are:

AmTest File No.	Date Collected	Matrix	Sample Identification
94-A017918	09/22/94	Water	500 SLMS, 600 SP-1, 601 SP-4, Trip Blank
94-A017678	09/20/94	Water	174-G-15S, 175 G-7S, 176 G-7D, 177 G-12
94-A015633	08/23/94	Water	162 G-13D
94-A015040	08/12/94	Water	152 G-15S, 153 G-7S, 154 G-7D, 155 G-12D, 156 G-8D1, 157 G-8D2, 158 G-6B, 159 G-11S
94-A014941	08/11/94	Water	144 G-2D, 145 G-1D, 146 G-9S, 147 G-9D, 148 G-10S, 149 G-10D, 150 G-14S, 151 G-14D
94-A014872	08/11/94	Water	140 NSDP, 138 G-3A, 141 G-4A
94-A013995	07/27/94	Water	120 G-6A, 123 NSDP
94-A013497	07/19/94	Water	G-12, G-1D, G-6B
94-A013210	07/13/94	Water	2 G-15S, 3 G-7S, 4 G-7D

AmTest File No. = AmTest identification number of first sample listed on the report.

METHODS OF ANALYSIS

Parameter	Technique	Method
pH	Electrometric	EPA 150.1
Alkalinity (as CaCO3)	Titrimetric	EPA 310.1
Hardness (as CaCO3)	Gravimetric	EPA 130.2
Chloride	Titrimetric	EPA 325.2
Conductivity	Electrometric	EPA 120.1
Sulfate	Turbidimetric	EPA 375.4
Total Coliforms	Membrane Filter	SM 9222B[a]
Fecal Coliforms	Membrane Filter	SM 9222D[a]
Chemical Oxygen Demand	Colorimetric	EPA 410.4
Biochemical Oxygen Demand	Electrometric	EPA 405.1
Total Organic Carbon	Oxidation	EPA 415.1

Parameter	Technique	Method
Ammonia Nitrogen	Colorimetric	EPA 350.1
Total Oil and Grease	Spectrophotometric	EPA 413.2
Total Cyanide	Titrimetric	EPA 335.2
Ortho-Phosphate	Colorimetric	EPA 365.2
Nitrate & Nitrite Nitrogen	Colorimetric	EPA 353.2
Nitrite Nitrogen	Spectrophotometric	EPA 354.1
Total Suspended Solids	Gravimetric	EPA 160.2
Metals[b]	ICP, AA, Cold Vapor	EPA 200 Series
Volatile Organic Compounds (VOCs)	GC/MS	EPA 624
Total Volatile Suspended Solids (TVSS)	Gravimetric	EPA 160.4[c]
Turbidity	Nephelometric	EPA 180.1
Semivolatile Organic Compounds	GC/MS	EPA 625
Pesticides and PCBs	GC/ECD	EPA 608

Notes:

a - Standard Methods for the Examination of Water and Wastewater.
b - Includes arsenic, barium, cadmium, chromium, copper, iron, mercury, magnesium, manganese, nickel, lead, selenium, silver, and zinc.
c - Method not identified; assumed to be EPA 160.4.

The laboratory has grouped analytical parameters in their reports. For ease of presentation, these groupings (listed below) are used in this data quality review.

Bacteriological (BACT): SM 19222B, SM 1922D

Conventionals (CONV): EPA Methods 120.1, 130.2, 150.1, 160.2, 160.4, 180.1, 310.1, 325.2, 335.2, 350.1, 353.2, 354.1, 365.2, 375.4, 405.1, 410.4, 413.2, 415.1

Metals (MET): EPA Methods 200.7, 206.2, 239.2, 245.1, 270.2

Organics (ORG): EPA Methods 608, 624, 625

LABORATORY QUALITY CONTROL

Method Blanks : Analytes were not detected at or above their associated method detection limit (MDL) in any blanks except as follows:

ORG

AmTest File No. 94-A014872: Methylene chloride was detected in the blank at 1.0 μg/L, and in associated sample 141 G4-A at 3.8 μg/L. The methylene chloride results for sample 141 G4-A should be flagged U, considered not detected, and the methylene chloride MDL considered to be elevated to 3.8 μg/L for this sample batch.

AmTest File Nos. 94-A014941 and 94-A013210: Methylene chloride (a common laboratory contaminant) was detected in the method blank by EPA Method 8260, a VOC method comparable to EPA 624, at 1.0 μg/L and 2.0 μg/L, respectively. Methylene chloride was not detected in any associated samples.

Metals

AmTest File No. 94-A017918: Zinc was detected in the blank at 0.006 mg/L, and in associated sample 601 SP-4 at 0.019 mg/L. The zinc result for sample 601 SP-4 should be flagged U and considered not detected.

AmTest File No. 94-A013497: Selenium and zinc were detected in the blank at 0.001 mg/L; zinc was detected in associated samples G-12 and G-6B at 0.002 mg/L. Both sample detections of zinc should be flagged U and considered not detected.

AmTest File No. 94-A013210: Iron was detected in the blank at 0.01 mg/L; iron detections in associated samples are considered not affected and data flagging is not recommended.

Matrix Spike/Matrix Spike Duplicates: Matrix spike (MS)/matrix spike duplicate (MSD) information is not provided for the following AmTest file numbers: 94-A017678, 94-A015633, 94-A014872, and 94-A013995. Other reports provide matrix spike/matrix spike duplicate percent recovery data, but laboratory control limits are not reported, and in some case, matrix spike concentrations are not reported. Without this information, it is difficult to assess laboratory performance. MS/MSD data were evaluated against EPA guidelines where possible; see the following discussions:

Pesticides and PCBs

AmTest File No. 94-A017918: Laboratory control limits were not available. MS and MSD recoveries of aldrin and p,p'-DDT fell below EPA advisory limits for a similar analytical method. AGI recommends the County obtain AmTest control limits for this parameter so a more comprehensive evaluation can be performed.

CONV

AmTest File No. 94-A015040: MS and MSD recoveries were reported for chloride and sulfate analyses. Spike concentrations were reported to be 50 and 100 mg/L, respectively, or 50 and 100 times the MDL. When spike concentrations are this high, percent recovery may not be an accurate indication of laboratory accuracy during analysis of samples with low analyte concentrations.

AmTest File No. 94-14941: Spike concentrations for TOC, chloride, ammonia-nitrogen, and sulfate ranged from 40 to 100 times the analyte MDL. See discussion above. Nitrate + nitrite-nitrogen and nitrite-nitrogen spike concentrations were 25 and 12.5 times the associated MDL, and are considered acceptable.

Metals

AmTest File No. 94-A014941: Spike concentrations were reported to range from 0.5 to 1 mg/L, or 50 to 500 times the analyte MDL. See CONV discussion above.

Duplicates : Duplicate sample information was provided for CONV and MET in 94-A015040, 94-A014941, 94-A013497, and 94-A013210. Duplicate sample information was not provided for other AmTest file numbers. Duplicate sample analysis is required by some of the EPA methods performed and should be provided with all laboratory reports. These data are used to evaluate laboratory precision. AGI recommends the laboratory be requested to provide these data.

Blank Spikes : Blank spike results were not provided.

Surrogates : Surrogate spike percent recoveries were provided for ORG analyses; however, laboratory control limits for acceptable recoveries were not provided. Without this information, it is difficult to assess laboratory performance on individual samples. Reported recoveries generally fell within EPA accepted limits for similar analytical methods, and are thus considered to indicate satisfactory laboratory performance.

HOLDING TIMES

Analysis dates were provided for most samples. If not provided, the date of report issuance was used to verify holding time compliance. Holding time requirements were met except as follows:

TVSS

Amtest File No. 94-A017918: Samples 600 SP-1 and 601 SP-4 were analyzed one day outside of holding time. Both reported results should be flagged UJ to indicate it is estimated there are no detections at the stated detection limit.

pH

Recommended holding time is specified to be immediate. Analyses for pH outside of holding time occurred as follows: 94-A017918 (samples held 6 days), 94-A017678 (sample held 2 days) 94-A015040 (analysis date not reported), 94-A013497 (samples held 2 days), and 94-A013210 (samples held 2 days). Results for samples held 2 days or more may have been affected, and should be considered estimated values.

Fecal Coliform

AmTest File No. 94-A014872: Date of analysis for this parameter is listed as 8/10/94, 2 days past the sample collection date of 8/10/94. Recommended holding time for this parameter is 6 to 9 hours. It is not clear from the laboratory report whether the analysis was begun or completed on 8/10/94. If it was begun on 8/10/94, sample results were likely compromised, and should be regarded as estimated. AGI recommends clarifying this issue with the laboratory.

AmTest File Nos. 94-A013995 and 94-A013497. Dates of analysis for this parameter are listed 7/28/94 and 7/20/94, respectively, which is likely a minimum of 17 hours past the sample collection times. See discussion above.

FIELD QUALITY CONTROL

Trip Blanks : One trip blank was analyzed, associated with AmTest File No. 94-A017918. Methylene chloride was detected at 1.7 μg/L. Associated samples 600 SP-1 and 601 SP-4 contained methylene chloride at 1.5 and 3.3 μg/L, respectively. The associated method blank was free of contamination. Because the methylene chloride detections are all approximately the same concentration, it is not likely the trip blank was contaminated during sample shipment or storage. Since the trip blank is prepared in the laboratory and methylene chloride is a common laboratory contaminant, it was likely introduced during preparation, preservation, or analysis. Associated sample detections may have been similarly affected and are therefore flagged (J) and regarded as estimates.

A trip blank should be included and analyzed with each shipment of water samples to be analyzed for VOCs for complete data quality assessment.

Field Blanks : Were not analyzed.

Field Duplicates : Were not analyzed.

Rinsate : Were not analyzed.

The various field quality control samples listed above can provide a means to evaluate field procedures, including equipment decontamination, and field precision. Implementation of a field data collection quality control program is recommended during any sampling rounds for which data quality assessment will be performed.

SUMMARY

Data were reviewed based on available quality control information. Additional quality control data were not requested by the County or AGI. Data were generally considered acceptable, with the following exceptions:

The following analytes are considered not detected due to laboratory contamination:

Methylene chloride in sample 141 G4-A
Zinc in samples 601 SP-4, G-12, and G-6B

Fecal coliform results in Am Test File Nos. 94-A014872, 94-A013497, and A013995 should be considered estimated unless it can be determined that analyses were begun within recommended holding time.

pH results in AmTest File Nos. 94-A017918, 94-A017678, 94-A015040 (analysis date not reported), 94-A013497, and 94-A013210 should be considered estimated unless it can be determined they were analyzed within approximately 24 hours of collection.

TVSS results for samples 600 SP-1 and 601 SP-4 should be flagged UJ and considered estimated nondetections due to holding time exceedance.

Methylene chloride results for samples 600 SP-1 and 601 SP-4 are flagged (J) and regarded as estimates due to contamination in the associated trip blank.

Note that QC data were not available for all analyses performed, and it was not always possible to determine relevance of the provided QC data to laboratory performance on environmental samples.

For complete analytical data validation, AGI recommends the County consider requesting that future sample analysis reports include complete quality control data in the form of method blank results, matrix spike/matrix spike duplicate percent recoveries and RPDs, duplicate sample RPDs, blank spike percent recoveries where applicable, surrogate spike percent recoveries, and all associated laboratory control limits and matrix spike concentrations.

AGI
TECHNOLOGIES

CHEMICAL DATA QUALITY REVIEW

Project Name: Snohomish County/Cathcart Landfill
Project No.: 15,512.108

AGI Technologies (AGI) performed a general chemical data quality review of fourth quarter 1994 surface and groundwater sampling results for the Cathcart Landfill. Results of associated laboratory method blanks, matrix spike/matrix spike duplicate (MS/MSD) percent recoveries and relative percent differences (RPDs), surrogate spike percent recoveries, accompanying chromatography, methods of analysis, and holding time requirements were evaluated. Findings are summarized below.

The laboratory reports reviewed are:

AmTest File No.	Date Collected	Matrix	Sample Identification
94-A019149	10/11/94	Water	8G-7S, 9G-7D
94-A019630	10/18/94	Water	17 G-15S, 18 G-12D, 19 G-6B
94-A020182	10/27/94	Water	111 NSDP
94-A020186	10/27/94	Water	110 G-4A
94-A020442	11/01/94	Water	115 A, 116 A-1, 117 B, 118 J, 119 F
94-A021112	11/15/94	Water	44 D-1
94-A021114	11/15/94	Water	43 W-1
94-A021217	11/17/94	Water	49 D-1
94-A021550	11/23/94	Water	52 G-15S, 53 G-7S, 54 G-7D, 55 G-12D
94-A021717	11/29/94	Water	60 G-1D, 61 G-2D
94-A021851	11/30/94	Water	63 G-6B, 64 G-6A
94-A021912	12/01/94	Water	67 G-13B, 68 G-14B, 69 G-14D
94-A021965	12/02/94	Water	150 A-1, 151 A, 152 B-1, 153 F, 154 D, 155 NSPD, 156 I, 157 J
94-A022408	12/09/94	Water	68 F, 69 D
94-A022800	12/14/94	Water	76 G-15S, 77 G-7S, 78 G-7D, 79 G-12, 80 G-6B
94-A022927	12/16/94	Water	82 G-9S, 83 G-9D
94-A023123	12/20/94	Water	90 G-10S, 91 G-10D
94-A023199	12/21/94	Water	85 G-11S, 86 G-8D1, 87 G-8D2
94-A023797	12/29/94	Water	172 G-1A, 173 G-6A, 174 G-3

AmTest File No. = AmTest identification number of first sample listed on the report.

METHODS OF ANALYSIS

Parameter	Technique	Method
pH	Electrometric	EPA 150.1
Hardness (as CaCO3)	Gravimetric	EPA 130.2
Chloride	Titrimetric	EPA 325.2
Conductivity	Electrometric	EPA 120.1
Sulfate	Turbidimetric	EPA 375.4
Total Coliforms	Membrane Filter	SM 9222B[a]
Fecal Coliforms	Membrane Filter	SM 9222D[a]
Chemical Oxygen Demand	Colorimetric	EPA 410.4
Biochemical Oxygen Demand	Electrometric	EPA 405.1
Total Organic Carbon	Oxidation	EPA 415.1
Ammonia Nitrogen	Colorimetric	EPA 350.1
Nitrate & Nitrite Nitrogen	Colorimetric	EPA 353.2
Nitrite Nitrogen	Spectrophotometric	EPA 354.1
Metals[b]	ICP, AA, Cold Vapor	EPA 200 Series
Volatile Organic Compounds (VOCs)	GC/MS	EPA 624
Turbidity	Nephelometric	EPA 180.1

Notes:

- a - Standard Methods for the Examination of Water and Wastewater.
- b - Includes arsenic, barium, cadmium, chromium, copper, iron, mercury, manganese, nickel, lead, selenium, silver, and zinc.

The laboratory has grouped analytical parameters in their reports. For ease of presentation, these groupings (listed below) are used in this data quality review.

Bacteriological (BACT):	SM 19222B, SM 1922D
Conventionals (CONV):	EPA Methods 120.1, 130.2, 150.1, 180.1, 325.2, 350.1, 353.2, 354.1, 375.4, 405.1, 410.4, 415.1
Metals (MET):	EPA Methods 200.7, 206.2, 239.2, 245.1, 270.2
Organics (ORG):	EPA Method 624

LABORATORY QUALITY CONTROL

Method Blanks : Analytes were not detected at or above their associated method detection limit (MDL) in any blanks except as follows:

ORG

AmTest File Nos. 94-A019149, 94-A019630, and 94-A020186: Methylene chloride (a common laboratory contaminant) was detected in the method blank by EPA Method 8260, a VOC method comparable to EPA 624, at 2.0 μg/L, 5.0 μg/L, and 1.0 μg/L, respectively. Methylene chloride was not detected in any associated samples.

AmTest File No. 94-A021114: Methylene chloride was detected in the blank at 2.0 μg/L, and in associated sample 43 W-1 at 3.0 μg/L. The methylene chloride results for sample 43 W-1 should be flagged U, considered not detected, and the methylene chloride MDL considered to be elevated to 3.0 μg/L for this sample batch.

AmTest File No. 94-A021717: Methylene chloride was detected in the blank at 5.0 μg/L and in associated samples 60 G-1D and 61 G-2D at 1.0 and 1.1 μg/L, respectively. These sample results should be flagged U, considered not detected, and the methylene chloride MDL considered elevated to 5.0 μg/L for this sample batch.

AmTest File No. 94-A021912: Methylene chloride was detected in the blank at 4.0 μg/L and in associated samples 67 G-13D and 69 G-14D at 1.4 and 1.0 μg/L, respectively. These sample detections should be flagged U, considered not detected, and the methylene chloride MDL considered elevated to 4.0 μg/L for this sample batch.

AmTest File No. 94-A022927: Methylene chloride was detected in the blank at 2.0 μg/L and in associated samples 82 G-9S and 83 G-9D at 1.2 and 1.4 μg/L, respectively. These sample detections should be flagged U, considered not detected, and the methylene chloride MDL considered elevated to 2.0 μg/L for this sample batch.

AmTest File No. 94-A023123: Methylene chloride was detected in the blank at 1.0 μg/L and in associated samples 90 G-10S and 91 G-10D at 1.9 and 2.5 μg/L, respectively. These sample detections should be flagged U, considered not detected, and the methylene chloride MDL considered elevated to 2.5 μg/L for this sample batch.

Metals

AmTest File Nos. 94-A020442, 94-A021912, and 94-A021965: Copper was detected in the blank at 0.006, 0.005, and 0.006 mg/L, respectively, and in associated samples 116 A-1; 117 B, 118 J, 119 F, 67 G-13D, 68 G-14D, 69 G-14D, 150 A-1, 152 B-1, 154D, 155 NSPD, and 157 J at similar concentrations. The copper results for these samples should be flagged U and considered not detected.

AmTest File No. 94-A02112: Copper was detected in the blank at 0.002 mg/L, but not in the associated sample. Data are not considered to be affected.

AmTest File No. 94-A021114: Iron and zinc were detected in the blank at 0.01 and 0.005 mg/L, respectively; iron and zinc detections in associated sample 43 W-1 are considered not affected and data flagging is not recommended.

AmTest File No. 94-A021217: Copper and zinc were detected in the blank at 0.002 and 0.005 mg/L, respectively; copper and zinc were detected in associated sample 49 D-1 at 0.009 and 0.016 mg/L, respectively. These results should be flagged U and considered not detected.

AmTest File No. 94-A021717: Copper was detected in the blank at 0.005 mg/L. Copper was not detected in associated samples. Data are not considered to be affected.

Matrix Spike/Matrix Spike Duplicates: Matrix spike (MS)/matrix spike duplicate (MSD) information is not provided for the following AmTest file numbers: 94-A020182, 94-A021112, 94-A021114, 94-A021217 (MS/MSD for ORG only), 94-A021851, 94-A022408, 94-A022800, 94-A022927 (MS/MSD for ORG only), 94-A023199, and 94-A023797. Other reports provide matrix spike percent recovery data, but laboratory control limits are not reported, and in some cases, matrix spike concentrations are not reported. Without this information, laboratory performance cannot be completely assessed. MS/MSD data were evaluated against EPA guidelines where possible; see the following discussions:

CONV

AmTest File No. 94-A020442: MS percent recoveries were reported for TOC, chloride, ammonia nitrogen, nitrate/nitrite nitrogen, nitrite nitrogen, and sulfate analyses. Spike concentrations were reported to be between 25 and 50 times the MDL. When spike concentrations are this high, percent recovery may not be an accurate indication of laboratory accuracy during analysis of samples with low analyte concentrations.

AmTest File No. 94-A021550: MS percent recoveries were reported for chloride and sulfate analyses. Spike concentrations were reported to be 50 and 200 mg/L, respectively, or 50 and 200 times the MDL. See discussion above.

Metals

AmTest File No. 94-A020442: Spike concentrations were reported to range from 0.025 to 1 mg/L, or 25 to 500 times the analyte MDL. See CONV discussion above.

Duplicates : Duplicate sample information was provided for CONV and MET in 94-A020442, 94-A021550, 94-A021912, and 94-A021965. Duplicate sample information was not provided for other AmTest file numbers. Duplicate sample analysis is required by some of the EPA methods performed and should be provided with all laboratory reports. These data are used to evaluate laboratory precision. AGI recommends the laboratory be requested to provide these data for complete data quality review.

Blank Spikes : Blank spike results were not provided.

Surrogates : Surrogate spike percent recoveries were provided for ORG analyses; however, laboratory control limits for acceptable recoveries were not provided. Without this information, laboratory performance on individual samples cannot be completely assessed. Reported recoveries generally fell within EPA accepted limits for similar analytical methods, and are thus considered to indicate satisfactory laboratory performance.

HOLDING TIMES

Analysis dates were provided for most samples. If not provided, the date of report issuance was used to verify holding time compliance. Holding time requirements were met except as follows:

- pH

  EPA recommends holding time for pH analysis be immediate. Analyses of pH outside of holding time occurred as follows: 94-A019630 (samples held 2 days), 94-A021112 (sample held 2 days) 94-A021851 (samples held 2 days), 94-A021965 (samples held 3 days), 94-A022408 (samples held 3 days), and 94-A022927 (samples held 3 days). Results for samples held 2 days or more may have been affected, and should be considered estimated values.

  Total Coliform

  AmTest File Nos. 94-A019149, 94-A019630, 94-A020442, 94-A021717, 94-A021912, 94-A022927, and 94-A023123: Dates of analysis for this parameter are listed as 1 day past sample collection dates. Recommended holding time for this parameter is 6 to 9 hours. It is not clear from the laboratory reports whether the analysis was begun or completed on the listed dates. If it was begun on the listed dates, sample results were likely compromised, and should be regarded as estimated for future sampling rounds. The County may want to consider clarifying this issue with the laboratory.

FIELD QUALITY CONTROL

Trip Blanks : Were not analyzed

A trip blank should be included and analyzed with each shipment of water samples to be analyzed for VOCs for complete data quality assessment.

Field Blanks : Were not analyzed.

Field Duplicates : Were not analyzed.

Rinsate : Were not analyzed.

The various field quality control samples listed above provide a means to evaluate field procedures, including equipment decontamination, and field precision. Implementation of a field data collection quality control program is recommended during any sampling rounds for which data quality assessment will be performed.

SUMMARY

Data were reviewed based on available quality control information. Additional quality control data were not requested by the County or AGI. Data were generally considered acceptable, with the following exceptions:

The following analytes are considered not detected due to laboratory contamination:

Methylene chloride in samples 43 W-1, 60 G-1D, 61 G-2D, 67 G-13D, 69 G-14D, 82 G-9S, 83 G-9D, 90 G-10S, and 91 G-10D

Copper in samples 116 A-1, 117 B, 118 J, 119 F, 67 G-13D, 68 G-14D, 69 G-14D, 150 A-1, 152 B-1, 154D, 155 NSPD, 157 J, 49 D-1

Zinc in sample 49 D-1

Total coliform results in Am Test File Nos. 94-A019149, 94-A019630, 94-A020442, 94-A-21717, 94-A021912, 94-A022927, and 94-A023123 should be considered estimated unless it can be determined that analyses were begun within recommended holding time.

pH results in AmTest File Nos. 94-A019630, 94-A021112, 94-A021851, 94-A021965, 94-A022408, and 94-A022927 should be considered estimated unless it can be determined they were analyzed within approximately 24 hours of collection.

Note that QC data were not available for all analyses performed, and it was not always possible to determine relevance of the provided QC data to laboratory performance on environmental samples.

For complete analytical data validation, AGI recommends the County consider requesting that future sample analysis reports include complete quality control data in the form of method blank results, matrix spike/matrix spike duplicate percent recoveries and RPDs, duplicate sample RPDs, blank spike percent recoveries where applicable, surrogate spike percent recoveries, and all associated laboratory control limits and matrix spike concentrations.

APPENDIX G

Landfill Effluent Chemistry

Table G–1
Landfill Effluent Chemistry – General Parameters

Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

			Sample I.D.	
Parameter	Detection Limit	Date Sampled	SP–1	SP–4
pH		12/19/93	7.0	6.6
		09/22/94	7.4	7.8
Total Alkalinity (mg/L as $CaCO_3$)	1.0	12/19/93	2,400	740
	1.0	09/22/94	3,600	1,400
Biochemical Oxygen Demand (mg/L)	10	12/19/93	ND	ND
	10	09/22/94	45	14
Chemical Oxygen Demand (mg/L)	10	12/19/93	330	88
	10	09/22/94	170	160
Specific Conductance (μmhos/cm)	0.5	12/19/93	6,300	3,200
	0.5	09/22/94	12,000	5,600
Total Cyanide (mg/L)	0.005	12/19/93	0.062	ND
	0.005	09/22/94	0.017	ND
Ammonia Nitrogen (mg/L)	0.005	12/19/93	270	63
	0.005	09/22/94	500	130
Total Oil and Grease (mg/L)	1.0	12/19/93	ND	ND
	1.0	09/22/94	ND	ND
Ortho–Phosphate (mg/L)	0.005	12/19/93	0.130	0.074
	0.005	09/22/94	1.6	0.27
Total Suspended Solids (mg/L)	1.0	12/19/93	20	12
	1.0	09/22/94	1.0	1.0
Volatile Suspended Solids (mg/L)	1.0	12/19/93	ND	ND
	1.0	09/22/94	ND	ND
Sulfate (mg/L)	10	12/19/93	48	200
	10	09/22/94	140	27
Phenol	0.005	12/19/93	0.010	ND
	0.005	09/22/94	NA	NA

Notes:

ND – Not detected.
NA – Not analyzed.
mg/L – Milligrams per liter.
μmhos/cm – Micromhos per centimeter.

Table G–2
Landfill Effluent Chemistry – Total Metals

Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Metal	Detection Limit (mg/L)	Date Sampled	Sample I.D.	
			SP–1	SP–4
Antimony	0.02	12/19/93	ND	ND
	0.02	09/22/94	NA	NA
Arsenic	0.001	12/19/93	0.005	0.006
	0.001	09/22/94	ND	ND
Beryllium	0.005	12/19/93	ND	ND
	0.005	09/22/94	NA	NA
Cadmium	0.002	12/19/93	ND	ND
	0.002	09/22/94	ND	ND
Chromium	0.006	12/19/93	0.011	ND
	0.006	09/22/94	0.014	ND
Copper	0.002	12/19/93	0.010	0.005
	0.002	09/22/94	ND	ND
Iron	0.01	12/19/93	7	8.3
	0.01	09/22/94	4.2	1.9
Mercury	0.0002	12/19/93	ND	ND
	0.0002	09/22/94	ND	ND
Magnesium	0.10	12/19/93	130	46
	0.10	09/22/94	200	68
Nickel	0.01	12/19/93	0.10	0.04
	0.01	09/22/94	0.16	0.04
Lead	0.001	12/19/93	ND	ND
	0.001	09/22/94	0.002	0.006
Selenium	0.001	12/19/93	ND	ND
	0.001	09/22/94	NA	NA
Silver	0.01	12/19/93	ND	ND
	0.01	09/22/94	ND	ND
Thallium	0.001	12/19/93	ND	ND
	0.001	09/22/94	NA	NA
Zinc	0.002	12/19/93	0.034	0.019
	0.002	09/22/94	0.21	0.019

Notes:

mg/L – Milligrams per liter.
NA – Not analyzed.
ND – Not detected.

Table G-3
Landfill Effluent Chemistry – Pesticides and PCBs

Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Compound	Detection Limit (µg/L)	Date Sampled	Sample I.D. SP-1	SP-4
			µg/L	
alpha-BHC	0.03	12/19/93	ND*	ND
	0.03	09/22/94	ND	ND
Lindane	0.03	12/19/93	ND*	ND
	0.03	09/22/94	ND	ND
Heptachlor	0.02	12/19/93	ND*	ND
	0.02	09/22/94	ND	ND
Aldrin	0.03	12/19/93	ND*	ND
	0.03	09/22/94	ND	ND
beta-BHC	0.04	12/19/93	ND*	ND
	0.04	09/22/94	ND	ND
delta-BHC	0.05	12/19/93	ND*	ND
	0.05	09/22/94	ND	ND
Heptachlor Epoxide	0.03	12/19/93	ND*	ND
	0.03	09/22/94	ND	ND
Endosulfan I	0.04	12/19/93	ND*	ND
	0.04	09/22/94	ND	ND
pp-DDT	0.1	12/19/93	ND*	ND
	0.1	09/22/94	ND	ND
Dieldrin	0.04	12/19/93	ND*	ND
	0.04	09/22/94	ND	ND
Endrin	0.05	12/19/93	ND*	ND
	0.05	09/22/94	ND	ND
pp-DDE	0.04	12/19/93	ND*	ND
	0.04	09/22/94	ND	ND
Endosulfan II	0.03	12/19/93	ND*	ND
	0.03	09/22/94	ND	ND
pp-DDT	0.1	12/19/93	ND*	ND
	0.1	09/22/94	ND	ND
Endrin Aldehyde	0.1	12/19/93	ND*	ND
	0.1	09/22/94	ND	ND
Endosulfan Sulfate	0.08	12/19/93	ND*	ND
	0.08	09/22/94	ND	ND
Methoxychlor	0.2	12/19/93	ND*	ND
	0.2	09/22/94	ND	ND
Toxaphene	1	12/19/93	ND*	ND
	1	09/22/94	ND	ND
Chlordane	0.5	12/19/93	ND*	ND
	0.5	09/22/94	ND	ND
PCBs				
Arochlor 1016	0.5	12/19/93	ND*	ND
	0.5	09/22/94	ND	ND
Arochlor 1221	2	12/19/93	ND*	ND
	2	09/22/94	ND	ND
Arochlor 1232	0.5	12/19/93	ND*	ND
	0.5	09/22/94	ND	ND
Arochlor 1242	0.5	12/19/93	ND*	ND
	0.5	09/22/94	ND	ND
Arochlor 1248	0.5	12/19/93	ND*	ND
	0.5	09/22/94	ND	ND
Arochlor 1260	0.5	12/19/93	ND*	ND
	0.5	09/22/94	ND	ND

Notes:

*Detection limit twice stated amount for SP-1 on 12/19/93.
ND – Not detected. NS – Not sampled. µg/L – Micrograms per liter.

Table G–4
Landfill Effluent Chemistry – Volatile Organic Compounds

Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Compound	Detection Limit (µg/L)	Date Sampled	Sample I.D. SP–1	SP–4
			µg/L	
Chloromethane	5.0	1219/93	ND	ND
	5.0	09/22/94	ND	ND
Vinyl Chloride	5.0	1219/93	ND	5.4
	5.0	09/22/94	ND	ND
Bromomethane	5.0	1219/93	ND	ND
	5.0	09/22/94	ND	ND
Chloroethane	5.0	1219/93	ND	ND
	5.0	09/22/94	ND	ND
Trichlorofluoromethane	1.0	1219/93	ND	ND
	1.0	09/22/94	ND	ND
1,1–Dichloroethylene	1.0	1219/93	ND	ND
	1.0	09/22/94	ND	ND
Acetone	20	1219/93	ND	ND
	20	09/22/94	ND	ND
Carbon Disulfide	1.0	1219/93	ND	ND
	1.0	09/22/94	ND	ND
Methylene Chloride	1.0	1219/93	ND	1.2
	1.0	09/22/94	1.5	3.3
1,2–Dichloroethylene	1.0	1219/93	ND	2.9
	1.0	09/22/94	ND	ND
1,1–Dichloroethane	1.0	1219/93	1.7	6.7
	1.0	09/22/94	ND	ND
Vinyl Acetate	10	1219/93	ND	ND
	10	09/22/94	ND	ND
2–Butanone (MEK)	10	1219/93	ND	ND
	10	09/22/94	ND	ND
Chloroform	1.0	1219/93	ND	ND
	1.0	09/22/94	ND	ND
1,1,1–Trichloroethane	1.0	1219/93	ND	ND
	1.0	09/22/94	ND	ND
Carbon Tetrachloride	1.0	1219/93	ND	ND
	1.0	09/22/94	ND	ND
Benzene	1.0	1219/93	7.7	2.5
	1.0	09/22/94	3.9	ND
1,2–Dichloroethane	1.0	1219/93	ND	ND
	1.0	09/22/94	ND	ND
1,1,2–Trichloroethene	1.0	1219/93	ND	ND
	1.0	09/22/94	ND	ND
Bromodichloromethane	1.0	1219/93	ND	ND
	1.0	09/22/94	ND	ND
1,2–Dichloropropane	1.0	1219/93	1.9	2.0
	1.0	09/22/94	ND	ND
4–Methyl–2–Pentanone	10	1219/93	ND	ND
	10	09/22/94	ND	ND
Toluene	1.0	1219/93	1.6	4.8
	1.0	09/22/94	ND	ND

Table G–4
Landfill Effluent Chemistry – Volatile Organic Compounds

Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Compound	Detection Limit (µg/L)	Date Sampled	Sample I.D.	
			SP–1	SP–4
			µg/L	
cis–1,3–Dichloropropene	1.0	1219/93	ND	ND
	1.0	09/22/94	ND	ND
1,1,2–Trichloroethane	1.0	1219/93	ND	ND
	1.0	09/22/94	ND	ND
Tetrachloroethylene	1.0	1219/93	ND	ND
	1.0	09/22/94	ND	ND
2–Hexanone	10	1219/93	ND	ND
	10	09/22/94	ND	ND
Chlorodibromomethane	1.0	1219/93	ND	ND
	1.0	09/22/94	ND	ND
Chlorobenzene	1.0	1219/93	6.9	ND
	1.0	09/22/94	3.9	ND
Ethylbenzene	1.0	1219/93	32	4.7
	1.0	09/22/94	16	ND
Total Xylenes	1.0	1219/93	28	100
	1.0	09/22/94	13	ND
Styrene	1.0	1219/93	ND	ND
	1.0	09/22/94	ND	ND
Bromoform	1.0	1219/93	ND	ND
	1.0	09/22/94	ND	ND
1,1,2,2–Tetrachloroethane	1.0	1219/93	ND	ND
	1.0	09/22/94	ND	ND
trans–1,3–Dichloropropene	1.0	1219/93	ND	ND
	1.0	09/22/94	ND	ND
p–Dichlorobenzene	1.0	1219/93	10	5.8
	1.0	09/22/94	9.5	1.4

Notes:

ND – Not detected.
µg/L – Micrograms per liter.

Table G–5
Landfill Effluent Chemistry – Semivolatile Organic Compounds

Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Compound	Detection Limit (µg/L)	Date Sampled	Sample I.D. SP–1	SP–4
			µg/L	
n–Nitrosodimethylamine	5.0	12/19/93	ND	ND
	5.0	09/22/94	ND	ND
Aniline	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
Phenol	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
bis(2–Chloroethyl)ether	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
2–Chlorophenol	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
1,3–Dichlorobenzene	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
1,4–Dichlorobenzene	2.0	12/19/93	9.0	5.1
	2.0	09/22/94	7.6	ND
Benzyl Alcohol	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
1,2–Dichlorobenzene	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
2–Methylphenol	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
bis(2–Chloroisopropyl)ether	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
4–Methylphenol	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
n–Nitroso–di–n–propylamine	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
Hexachloroethane	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
Nitrobenzene	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
Isophorone	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
2–Nitrophenol	5.0	12/19/93	ND	ND
	5.0	09/22/94	ND	ND
2,4–Dimethylphenol	2.0	12/19/93	3.0	ND
	2.0	09/22/94	4.5	ND
Benzoic Acid	5.0	12/19/93	ND	ND
	5.0	09/22/94	ND	ND
bis(2–Chloroethoxy)methane	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
2,4–Dichlorophenol	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
1,2,4–Trichlorobenzene	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
Naphthalene	2.0	12/19/93	16	2.7
	2.0	09/22/94	24	ND
4–Chloroaniline	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND

Table G–5

Landfill Effluent Chemistry – Semivolatile Organic Compounds

Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Compound	Detection Limit (µg/L)	Date Sampled	Sample I.D.	
			SP–1	SP–4
			µg/L	
Hexachlorobutadiene	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
4–Chloro–3–methylphenol	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
2–Methylnaphthalene	2.0	12/19/93	3.5	ND
	2.0	09/22/94	6.3	ND
Hexachlorocyclopentadiene	5.0	12/19/93	ND	ND
	5.0	09/22/94	ND	ND
2,4,6–Trichlorophenol	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
2,4,5–Trichlorophenol	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
2–Chloronaphthalene	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
2–Nitroaniline	5.0	12/19/93	ND	ND
	5.0	09/22/94	ND	ND
Dimethylphthalate	2.0	12/19/93	ND	2.4
	2.0	09/22/94	ND	ND
Acenaphthylene	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
2,6–Dinitrotoluene	5.0	12/19/93	ND	ND
	5.0	09/22/94	ND	ND
3–Nitroaniline	5.0	12/19/93	ND	ND
	5.0	09/22/94	ND	ND
Acenaphthene	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
2,4–Dinitrophenol	10	12/19/93	ND	ND
	10	09/22/94	ND	ND
4–Nitrophenol	10	12/19/93	ND	ND
	10	09/22/94	ND	ND
Dibenzofuran	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
2,4–Dinitrotoluene	5.0	12/19/93	ND	ND
	5.0	09/22/94	ND	ND
Diethylphthalate	2.0	12/19/93	4.8	ND
	2.0	09/22/94	ND	ND
4–Chlorophenyl–phenyl ether	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
Fluorene	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
4–Nitroaniline	5.0	12/19/93	ND	ND
	5.0	09/22/94	ND	ND
4,6–Dinitro–2–methylphenol	5.0	12/19/93	ND	ND
	5.0	09/22/94	ND	ND
n–Nitrosodiphenylamine	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
Azobenzene	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND

Table G-5
Landfill Effluent Chemistry – Semivolatile Organic Compounds

Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Compound	Detection Limit (µg/L)	Date Sampled	Sample I.D.	
			SP-1	SP-4
			µg/L	
4-Bromophenyl-phenyl ether	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
Hexachlorobenzene	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
Pentachlorophenol	5.0	12/19/93	ND	ND
	5.0	09/22/94	ND	ND
Phenanthrene	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
Anthracene	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
Di-n-butylphthalate	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
Fluoranthene	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
Benzidine	50	12/19/93	ND	ND
	50	09/22/94	ND	ND
Pyrene	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
Butylbenzylphthalate	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
3-3-Dichlorobenzidine	3.0	12/19/93	ND	ND
	3.0	09/22/94	ND	ND
Benzo(a)anthracene	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
Chrysene	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
bis(2-Ethylhexyl)phthalate	2.0	12/19/93	ND	9.0
	2.0	09/22/94	ND	ND
Di-n-octylphthalate	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
Benzo(b)fluoranthene	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
Benzo(k)fluoranthene	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
Benzo(a)pyrene	2.0	12/19/93	ND	ND
	2.0	09/22/94	ND	ND
Indeno(1,2,3-cd)pyrene	4.0	12/19/93	ND	ND
	4.0	09/22/94	ND	ND
Dibenzo(a,h)anthracene	4.0	12/19/93	ND	ND
	4.0	09/22/94	ND	ND
Benzo(g,h,i)perylene	4.0	12/19/93	ND	ND
	4.0	09/22/94	ND	ND

Notes:

ND – Not detected.
NS – Not sampled.
µg/L – Micrograms per liter.

AGI
TECHNOLOGIES

APPENDIX H

Landfill Hydrologic Budget Analysis

APPENDIX H

Landfill Hydrologic Budget Analysis

The hydrologic budget analysis is summarized in Section 4.3. Details regarding formulation of the analysis are presented below.

BASIS FOR ANALYSIS

Monthly mean SP-1 flow data are the basis for the hydrologic budget analysis. Available information indicates all landfill fluids are routed through SP-1 prior to conveyance to the Pretreatment Facility. After correction for inflow to SP-1 from the North Pond and extraction well W-1 pumping, SP-1 is assumed to represent total flows discharging from the landfill.

Total landfill flows, as quantified at SP-1, are based on total sump pumping time converted by the County to total daily flows. County personnel have indicated these rates are calibrated on a periodic basis. It should be noted that the hydrologic budget assumes these flow values represent actual field conditions. Any error associated with the SP-1 flow values are carried through the analysis.

CONCEPTUAL MODEL

To determine relative magnitudes of groundwater inflows to the CLF, the landfill was conceptualized as a rectangular box with primary dimensions equal to those of the landfill, as shown on Figure 22. Horizontal inflows to the landfill occur at the south, east, and west faces of the model; upward inflow (upwelling) occurs at the model floor. Outflow from the model occurs at the north face and SP-1 (underdrain and leachate collection system).

As stated in Section 3.3.2, inflows to the landfill likely originate as:

- groundwater throughflow
- infiltrating Garden Creek flow loss
- infiltrating east side drainage ditch loss
- infiltrating South Pond loss
- construction features which reportedly exist in the vicinity of the South Pond

Flow contributions from each of these sources enters the landfill through one of the faces of the model.

FORMULATION OF ANALYSIS

The flow inflow/outflow balance was formulated as follows:

inflow: west face + south face + east face + cap runoff (directed into SP-1) + internal leachate + upwelling =

outflow: [underdrain + leachate outflow (SP-1)] + north face

Both wet and dry season flows were evaluated. The dry season was evaluated using SP-1, precipitation, and hydraulic gradient data from August and September 1994, which were the driest months of the year. Dry season flow magnitudes were assumed to represent baseline, or minimum conditions. The wet season was evaluated using data from November and December 1994; these were the most recent and wettest months available at the time of the analysis.

The following are more detailed formulations of the hydrologic budget equations for the two seasons:

Dry Season

$$GW_{south} + GW_{east} + GW_{west} + GW_{upwell} + \textit{internal leachate} = SP\text{-}1 + GW_{north}$$

where GW_{south}, GW_{east}, GW_{west} and GW_{north} were calculated as described above, internal leachate generation was assumed, and SP-1 flows were from the County's database. GW_{upwell} was the unknown parameter.

Wet Season

$$GW_{south} + GW_{east} + GW_{west} + GW_{upwell} + \textit{internal leachate} = SP\text{-}1 + GW_{north} - (R - ET) * f$$

where the same conditions described above exist and

R = rainfall
ET = evapotranspiration
and f = the fraction of the landfill's surface water routed to SP-1 (95%).

During November 1994, surface water was routed to SP-1 for 24 days. No surface water entered SP-1 during December, and the above equation was reduced to that used for the dry season analysis.

The various flows were determined as follows:

Surface Water : Surface water flow rates were measured at various locations along Garden Creek using existing V-notch weirs and the new weirs installed in 1994, the South Pond weir, and several culverts. Flow measurements were made between October 31 and December 19, 1994. These data are presented in **Table 1** of the text.

Cap Runoff : Cap runoff was estimated based on the difference between total rainfall and total evapotranspiration calculated for the cap using the Penman equation. This volume of surface water runoff was removed from the SP-1 flow volume for the periods of interest.

Groundwater Flows : The hydrologic budget analysis employed groundwater inflow through five flow faces: the west, south, east, and north walls of the landfill, and the landfill floor. Each of the faces comprised up to three hydrogeologic flow regimes: siltstone, till and fill, and alluvium. Siltstone, till, and fill are included in each of the faces; alluvium, which comprises the former Garden Creek channel, was included only in the south and north faces. The landfill floor was assumed to comprise only siltstone. Groundwater through each of these units was estimated based on the Darcy formula, as follows:

$$Q = K \times i \times A$$

where Q = groundwater flow (cubic feet per second)
K = hydraulic conductivity of the medium (feet/second)
i = hydraulic gradient (vertical head difference per horizontal distance)
A = effective saturated cross sectional area of the medium

Groundwater flow through the siltstone, till/fill, and alluvium was calculated based on hydraulic gradients determined based on water elevation differences between monitoring wells in proximity to the respective face. Groundwater elevations were obtained from monthly water levels measured by the County. Hydraulic conductivity values are based on the previous investigations for the CLF and adjoining RLF (*AGI: Summary Hydrogeologic Report for the Regional Landfill, 1995*) or were assumed based on known lithologic properties. Hydraulic parameters for the various units are summarized in **Table 3** of the text.

Considerations for groundwater flow through each landfill face are discussed below.

West Face : Groundwater inflow across the west face of the landfill occurs as seepage through the siltstone and shallow flow in the fill and till. As shown on the groundwater contour maps (**Figures 15 through 18**), groundwater flows toward the landfill at an oblique angle along the west side; the hydraulic gradient (water table slope) into the west face is therefore relatively low. The rate of groundwater seepage across the west face was assumed to be constant along its entire length.

Garden Creek flows parallel to the west side of the landfill along its entire length. Water infiltrating from the creek likely percolates downward until it reaches the water table and enters the groundwater. Due to reasons just described, some of this water likely does not flow toward the landfill. Additionally, the increase in groundwater flow across the west face caused by losses from Garden Creek is calculated in terms of increased saturated thickness in the Darcy formula presented above. Maximum loss measured along Garden Creek during wet season flow was approximately 3 gpm along its entire length along the landfill. Given the large saturated area of entire west face, the contribution from Garden Creek as groundwater flow across the west face is considered insignificant.

Garden Creek losses could enter the landfill through other pathways such as construction features; however, no such pathway has been identified.

South Face : Groundwater flow through the Garden Creek watershed flows directly into the south face of the landfill. Local sources of groundwater recharge at the landfill's south face include groundwater flow through the watershed, surface water infiltration from the South Pond and the south reach of Garden Creek, and physical flow pathways associated with landfill construction features that may still exist at the landfill's south end. These sources all contribute to movement of water across the south face of the landfill.

Groundwater flow across the south face occurs in the alluvium (original Garden Creek channel), till, and siltstone. The alluvium likely contributes the greatest magnitude of flow across the south landfill face. The till and siltstone likely allow markedly less flow due to their low hydraulic conductivities.

Surface water collected by the South Pond causes an increase in the pond water level between dry and wet seasons. As water elevations increase, hydraulic head at the pond base also increases, causing water to infiltrate into groundwater. This recharge to groundwater flow is assumed to contribute a significant portion of the flow across the south face of the landfill. County personnel have noted that the pond has never drained completely; this indicates the pond is likely an expression of the water table. Consequently, as long as surface water flows into the pond, it provides continuous recharge to the groundwater flowing toward the south face.

As described above, maximum loss measured along Garden creek during wet season flow was approximately 3 gpm for its entire length along the landfill. Based on this volume, it is unlikely the portion of the creek along the south face of the landfill contributes significantly to flows across the south face.

East Face : Groundwater inflow across the east face of the landfill consists of seepage through the bedrock and shallow flow in the fill and till. The groundwater divide, which generally corresponds to the topographic ridge east of the landfill, is relatively close to the east face. The hydraulic gradient here is therefore higher than at the west face. The rate of groundwater seepage was assumed to be constant across the entire east face.

Some portion of surface water infiltrating from the east side drainage ditch may enter groundwater; however, this process is likely identical to that described above for Garden Creek. The contribution to groundwater from the east side drainage ditch is therefore assumed to be insignificant.

Groundwater Upwelling : Groundwater upwelling cannot be measured due to lack of direct access to water and leachate levels at the base of the landfill excavation. Construction records indicate the integrity of the membrane liner was compromised during construction. This factor, coupled with chemical and volumetric evidence of commingling of leachate and groundwater, indicates that there is likely upward groundwater flow through the landfill base.

In the hydrologic budget analysis, groundwater upwelling was solved for as the unknown factor. As described above, all other inflows and outflows through the landfill faces were estimated based on hydraulic properties determined by the watershed balance, and SP-1 values were known. Because the surface area of the landfill base is on the order of 3 million square feet, upwelling across this face is likely significant.

Internal Leachate Generation : Additional water is contributed by internal leachate drainage resulting from refuse consolidation over time and delayed drainage of water trapped in the refuse after capping. The internally generated leachate volume was estimated at 5 gpm assuming no precipitation inflow through the landfill cap.

North Face : In addition to SP-1, the north face of the landfill constitutes a groundwater outflow pathway. This outflow is partitioned into the same three flow regimes as the south end of the landfill: the alluvial channel, till, and siltstone. Conditions are similar at both faces, except that the north face likely has a higher hydraulic gradient across it.

RESULTS

Estimated inflows and outflows for the 1994 dry (August and September) and wet (November and December) seasons are summarized in **Table 4** of the text. Relative magnitudes of these inflows for both seasons are illustrated in the pie diagram shown on **Figure 23** of the text.

Results of the analysis demonstrate the following:

- Groundwater upwelling is responsible for the largest share of inflow to the landfill. During December 1994, upwelling inflows were estimated to be approximately 70 gpm. In terms of the total flow rate, this inflow appears relatively high compared with the landfill faces. However, the corresponding flux rate for the upwelling term is approximately 2.5×10^{-5} gpm per square foot of landfill floor, based on landfill excavation dimensions of 3,000 feet (length) by 900 feet (width). December flux rates for the west and east faces are approximately 7×10^{-6} and 1×10^{-5} gpm.
- Inflow through the south landfill face is significant relative to the other faces. South face inflows are likely higher than the other faces due to flow through the alluvium and the relatively continuous recharge to groundwater from the South Pond.

SUMMARY

Our analysis indicates landfill inflows are ordered, from most to least significant, as follows:

1. Groundwater upwelling
2. South face inflow
3. Internal leachate drainage
4. East face inflow
5. West face inflow

Based on results of the watershed and landfill hydrologic budget analyses, we conclude the following:

- The results of the landfill hydrologic budget analysis indicate groundwater upwelling is significant. During the dry season, approximately 16 gpm of water enters the landfill excavation and exit through SP-1. Wet season groundwater upwelling may exceed 70 gpm.
- Flow through the alluvial channel at the south face of the landfill is also likely a large quantity. During the dry season, south face groundwater flow is approximately 4 gpm; during the wet season, this flow increases to approximately 14 gpm.
- Groundwater flows across the east and west faces of the landfill are not significant relative to the south face and upwelling inflows. The east and west face flows range from 0.1 gpm from the east and 0.4 gpm from the west during the wet season. Calculations for these flow values assume uniform flow through the till or bedrock along the entire length of the east and west faces.
- Internal drainage of leachate may be a significant source of landfill fluids, although it is currently impossible to quantify the volume contributed.

APPENDIX I

Alternative Cost Estimates

Table I–1
Cost Estimate

Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Lining Garden Creek

Item	Quantity	Price	Source	Cost
Excavation				
Excavate Soil (includes stockpiling)	7,640 c.y.	$15.00 /c.y.	Debco Construction	$114,600
Anchor Trench (excavation and backfill)	6,600 l.f.	$6.00 /l.f.	Debco Construction	$39,600
				$154,200
Underdrain Installation				
Drain Pipe (6" SDR11 perforated HDPE)	3,350 l.f.	$4.05 /l.f.	Familian Northwest, Inc.	$13,568
Piping Installation (excavation, backfill, and drain rock)	3,350 l.f.	$12.00 /l.f.	Debco Construction	$40,200
				$53,768
Lining – Materials/Installation				
Liner – 80–mil HDPE, textured (includes installation)	198,000 sqft	$0.75 /sqft	Gundle Plastics	$148,500
Geotextile – 8 oz nonwoven (includes installation)	198,000 sqft	$0.15 /sqft	Gundle Plastics	$29,700
Drain Rock (includes delivery)	1,260 c.y.	$14.30 /c.y.	Topsoils Northwest	$18,018
5/8–Crushed Rock (includes delivery)	2,444 c.y.	$12.98 /c.y.	Topsoils Northwest	$31,723
2"–4" Rock (includes delivery)	4,888 c.y.	$12.98 /c.y.	Topsoils Northwest	$63,446
Placing Materials	10,303 c.y.	$5.00 /c.y.	Debco Construction	$51,515
				$342,902
Mobilization		$35,000	Estimate	$35,000
Contingencies	25%		Estimate	$146,467
Sales Tax	8.2%			$60,052
			Subtotal	$792,389
Design/Const. Admin.				
Design	15%		Estimate	$118,858
Const. Admin.	15%		Estimate	$118,858
			Total	**$1,090,157**
Operation and Maintenance			Estimate	$3,000
			Annual Cost	**$3,000**

Table I–1
Cost Estimate

Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Lining South Stormwater Detention Pond

Item	Quantity	Price	Source	Cost
Excavation				
Excavate Soil (includes stockpiling)	10,667 c.y.	$10.00 /c.y.	Debco Construction	$106,670
Anchor Trench (excavation and backfill)	1,520 l.f.	$6.00 /l.f.	Debco Construction	$9,120
Soil and Wetland Plant Reastablisment		$30,000	Estimate	$120,000
				$235,790
Underdrain Installation				
Drain Pipe				
(4" Schedule 40 perforated PVC)	880 l.f.	$1.85 /l.f.	Familian Northwest, Inc.	$1,628
(6" SDR11 perforated HDPE)	100 l.f.	$4.05 /l.f.	Familian Northwest, Inc.	$405
Piping Installation (excavation, backfill, and drain rock)	980 l.f.	$10.00 /l.f.	Debco Construction	$9,800
				$11,833
Lining – Materials/Installation				
Liner – 80–mil HDPE, textured (includes installation)	144,000 sqft	$0.68 /sqft	Gundle Plastics	$97,920
Geotextile – 8 oz nonwoven (includes installation)	144,000 sqft	$0.12 /sqft	Gundle Plastics	$17,280
Drain Rock (includes delivery)	1,181 c.y.	$14.30 /c.y.	Topsoils Northwest	$16,888
Placing Materials	10,667 c.y.	$3.90 /c.y.	Debco Construction	$41,601
				$173,690
Manhole Installation				
Manhole	1	$1,025 /ea.	Means	$1,025
Excavate Soil (excavation, place, backfill)	28 ft	$4,350 /14 l.f.	Means	$17,400
Antifloatation Collar	1	$2,000 /ea.	Estimate	$2,000
				$20,425
Pump Installation				
Duplex Pump & Control Panel (includes installation)	1	$15,000 /ea.	Estimate	$15,000
Mobilization		$20,000	Estimate	$20,000
Contingencies	25%		Estimate	$119,184
Sales Tax	8.2%			$48,866
			Subtotal	$644,788
Design/Const. Admin.				
Corps of Engineers – Permitting		$25,000	Estimate	$25,000
Design	15%		Estimate	$96,718
Const. Admin.	15%		Estimate	$96,718
			Total	**$863,224**
Operation and Maintenance			Estimate	$1,000
			Annual Cost	**$1,000**

Table I–1
Cost Estimate
Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Lining East Ditch

Item	Quantity	Price	Source	Cost
Excavation				
Excavate Soil (includes stockpiling)	4,650 c.y.	$10.00 /c.y.	Debco Construction	$46,500
Anchor Trench (excavation and backfill)	5,400 l.f.	$6.00 /l.f.	Debco Construction	$32,400
				$78,900
Underdrain Installation				
Drain Pipe (4" Schedule 40 perforated PVC)	2,700 l.f.	$1.85 /l.f.	Familian Northwest, Inc.	$4,995
Piping Installation (excavation, backfill, and drain rock)	2,700 l.f.	$10.00 /l.f.	Debco Construction	$27,000
				$31,995
Lining – Materials/Installation				
Liner – 80–mil HDPE, textured (includes installation)	54,000 sqft	$0.68 /sqft	Gundle Plastics	$36,720
Geotextile – 8 oz nonwoven (includes installation)	54,000 sqft	$0.12 /sqft	Gundle Plastics	$6,480
Drain Rock (includes delivery)	333 c.y.	$14.30 /c.y.	Topsoils Northwest	$4,762
5/8–Crushed Rock (includes delivery)	667 c.y.	$12.98 /c.y.	Topsoils Northwest	$8,658
2"–4" Rock (includes delivery)	1,333 c.y.	$12.98 /c.y.	Topsoils Northwest	$17,302
Placing Materials	2,500 c.y.	$3.90 /c.y.	Debco Construction	$9,750
				$83,672
Mobilization		$15,000.00	Estimate	$15,000
Contingencies	25%		Estimate	$52,392
Sales Tax	8.2%			$21,481
			Subtotal	$283,439
Design/Const. Admin.				
Design	15%		Estimate	$42,516
Const. Admin.	15%		Estimate	$42,516
			Total	**$368,471**
Operation and Maintenance			Estimate	$1,000
			Annual Cost	**$1,000**

Table I–1
Cost Estimate

Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Medium Depth South Trench

Item	Quantity	Price	Source	Cost
Excavation				
Excavate Soil	27,800 c.y.	$9.00 /c.y.	Estimate	$250,200
Stockpile Soil (On–site)	27,800 c.y.	$20.00 /c.y.	Estimate	$556,000
				$806,200
Pipe Installation				
Drain Pipe (HDPE SDR 11 6" dia. slotted)	1,500 l.f.	$4.05 /l.f.	Distributor	$6,075
Piping Installation (labor)	1,500 l.f.	$5.00 /l.f.	Estimate	$7,500
3/4–Wash Rock	27,800 c.y.	$15.00 /c.y.	Estimate	$417,000
Backfill (labor and equipment)	27,800 c.y.	$3.44 /c.y.	Means p.41 Item 3040	$95,632
Compaction	27,800 c.y.	$0.15 /c.y.	Means p.35 Item 5060	$4,170
				$530,377
Pump Installation				
Pump/Controls	3	$4,000.00 /ea.	Estimate	$12,000
Installation	3	$400.00 /ea.	Means p.78 Item 1510	$1,200
Manifold Pipe (4" dia. PVC) (includes installation)	1,700 l.f.	$7.10 /l.f.	Means p.75 Item 2180	$12,070
Electrical			Estimate	$2,000
				$27,270
Mobilization		$100,000	Estimate	$100,000
Contingencies	25%		Estimate	$365,962
Sales Tax	8.2%			$150,044
			Subtotal	$1,979,853
Design/Const. Admin.				
Design	15%		Estimate	$296,978
Const. Admin.	15%		Estimate	$296,978
			Total	**$2,573,809**
Operation and Maintanence				
Power	1 yr	$0.10 /kw–hr	Estimate	$400
Pump Replacement	1 /yr	$1,235.00 /ea.	Estimate	$1,235
Maintenance	1 yr		Estimate	$2,100
			Annual Cost	**$3,735**

Table I–1
Cost Estimate
Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Deep Trench

Item	Quantity	Price	Source	Cost
Excavation				
Fill Material	70,600 c.y.	$8.00 /c.y.	Estimate	$564,800
Till Material	58,800 c.y.	$10.00 /c.y.	Estimate	$588,000
Drilling/Blasting	83,000 c.y.	$66.50 /c.y.	Means p.36 Item 2200	$5,519,500
Excavate Siltstone	83,000 c.y.	$20.00 /c.y.	Estimate	$1,660,000
Stockpile Soil (On–site)	212,400 c.y.	$20.00 /c.y.	Estimate	$4,248,000
				$12,580,300
Pipe Installation				
Drain Pipe–6" (HDPE SDR 9 6" dia. slotted)	6,350 l.f.	$10.00 /l.f.	Distributor	$63,500
Drain Pipe–8" (HDPE SDR 9 8" dia. blank)	2,000 l.f.	$10.00 /l.f.	Distributor	$20,000
3/4–Wash Rock	141,000 c.y.	$15.00 /c.y.	Estimate	$2,115,000
Pit Run Material	70,600 c.y.	$10.00 /c.y.	Estimate	$706,000
Backfill (labor & equipment)	212,400 c.y.	$3.44 /c.y.	Means p.41 Item 3040	$730,656
Compaction	212,400 c.y.	$0.15 /c.y.	Means p.35 Item 5060	$31,860
Piping Installation–6" (labor)	6,350 l.f.	$9.50 /l.f.	Estimate	$60,325
Piping Installation–8" (labor)	2,000 l.f.	$1.29 /l.f.	Means p.71 Item 1220	$2,580
				$3,729,921
Check Dams				
Bentonite/Cement Slurry Wall	3,080 c.y.	$22.00 /c.y.	Means p.33 Item 0100	$67,760
Special Construction Methods	3,080 c.y.	$50.00 /c.y.	Estimate	$154,000
				$221,760
Pump Installation				
Pump (3" dia. 1/2 H.P.)	20	$400.00 /ea.	Distributor	$8,000
Installation	20	$235.00 /ea.	Means p.78 Item 1510	$4,700
Manifold Pipe (4" dia. PVC)	7,000 l.f.	$7.10 /l.f.	Means p.75 Item 2180	$49,700
Electrical (equip. and labor)	20	$14,500.00 /ea.	Estimate	$290,000
Additional Monitoring Wells (20)	2,000 l.f.	$55.00 /l.f.	Estimate	$110,000
				$462,400
Mobilization		$200,000	Estimate	$200,000
Contingencies	25%		Estimate	$4,298,595
Sales Tax	8.2%			$1,762,424
			Subtotal	$23,255,400
Design/Const. Admin.				
Design	15%		Estimate	$3,488,310
Const. Admin.	15%		Estimate	$3,488,310
				$6,976,620
Modeling				
Monitoring Well Installation	1000 l.f	$60 /l.f.	Estimate	$60,000
Setup Computer Model		$40,000	Estimate	$40,000
Calibrate Computer Model		$20,000	Estimate	$20,000
Data Search		$10,000	Estimate	$10,000
Field Work		$15,000	Estimate	$15,000
Contingency	20%	$29,000	Estimate	$29,000
				$174,000
			Total	**$30,406,020**
Operation and Maintanence				
Power	1 yr	$0.10 /kw–hr	Estimate	$5,475
Pump Replacement	4 /yr	$635.00 /ea.	Estimate	$2,540
Maintenance	1 yr		Estimate	$10,400
			Annual Cost	**$18,415**

Table I–1
Cost Estimate
Snohomish Co. Public Works Dept./Cathcart Landfill
Snohomish County, Washington

Rock Fracturing/Extraction Wells

Item	Quantity	Price	Source	Cost
Rock Fracturing				
Drill Borings (Air Rotary)	26,000 l.f	$55.00 /l.f.	Estimate	$1,430,000
Fracture Rock	212 borings	$2,600.00 /boring	Estimate	$551,200
				$1,981,200
Pump Installation				
Pump (3" dia. 1/2 H.P.)	141	$400.00 /ea.	Distributor	$56,400
Installation	141	$235.00 /ea.	Means p.78 Item 1510	$33,135
Manifold Pipe (4" dia PVC) (includes installation)	7,000 l.f.	$7.10 /l.f.	Means p.75 Item 2180	$49,700
Electrical (equip. and labor)	141	$14,500.00 /ea.	Estimate	$2,044,500
Additional Monitoring Wells (20)	2,000 l.f.	$55.00 /l.f.	Estimate	$110,000
				$2,293,735
Mobilization		$200,000	Estimate	$200,000
Contingencies	25%		Estimate	$1,118,734
Sales Tax	8.5%			$458,681
			Subtotal	$6,052,350
Design/Const. Admin.				
Design	15%		Estimate	$907,852
Const. Admin.	15%		Estimate	$907,852
				$1,815,705
Modeling				
Monitoring Well Installation	1000 l.f	$60 /l.f.	Estimate	$60,000
Setup Computer Model		$40,000	Estimate	$40,000
Calibrate Computer Model		$20,000	Estimate	$20,000
Data Search		$10,000	Estimate	$10,000
Field Work		$15,000	Estimate	$15,000
Contingency	20%	$29,000	Estimate	$29,000
				$174,000
			Total	**$8,042,054**
Operation and Maintanence				
Power	1 yr	$0.10 /kw–hr	Estimate	$8,030
Pump Replacement	29 /yr	$635.00 /ea.	Estimate	$18,415
Maintenance	1 yr		Estimate	$20,800
			Annual Cost	**$47,245**