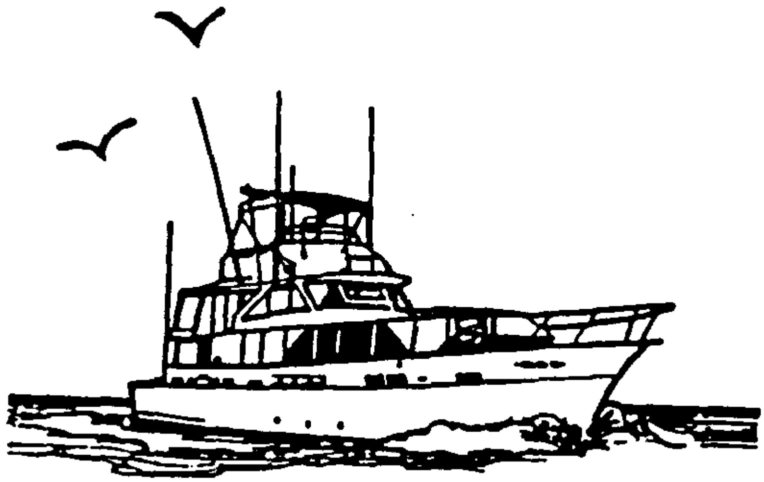
D-1107
C. 1
94100800

CITY OF WESTPORT
and
SOUTH BEACH AREA

GROUNDWATER CHARACTERIZATION STUDY



Prepared for:

City of Westport
506 N. Montesano St.
P.O. Box 505
Westport, WA 98595

Grays Harbor County
100 W. Broadway
P.O. Box 391
Montesano, WA 98563

Prepared by:

Consoer, Townsend & Associates, Inc.
733 Market Street, Suite 500
Tacoma, WA 98402

Robinson & Noble, Inc.
5915 Orchard Street W.
Tacoma, WA 98467

CONSOER
TOWNSEND
&
ASSOCIATES

94100800

CITY OF WESTPORT
and
SOUTH BEACH AREA

GROUNDWATER CHARACTERIZATION STUDY

Prepared for:

City of Westport
506 N. Montesano St
P. O. Box 505
Westport, WA 98595

Grays Harbor County
100 W. Broadway
P. O. Box 391
Montesano, WA 98563

Prepared By:

Consoer, Townsend & Associates
733 Market Street, Suite 500
Tacoma, WA 98402

Robinson & Noble, Inc.
5915 Orchard Street W
Tacoma, WA 98467

February, 1994

CERTIFICATE OF ENGINEER

The technical material and data contained in this report were prepared under the supervision and direction of the undersigned, whose seals as Professional Engineers, licensed to practice as such, are affixed below.

JOHN T. BARNES
STATE OF WASHINGTON
30121
REGISTERED
PROFESSIONAL ENGINEER

EXPIRES 7/12/94

CHANDLER L. ODELL
STATE OF WASHINGTON
14640
REGISTERED
PROFESSIONAL ENGINEER

EXPIRES 7/9/95

John T. Barnes, P.E.

Chandler L. Odell, P.E.

TABLE OF CONTENTS

LIST OF APPENDICES

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

This study represents the hydrogeologic assessment of the area north of the Grays Harbor-Pacific County line encompassing the Westport peninsula. The study includes the geologic definition of this area, placement of five new monitor wells and development of a numerical computer model to assist in the evaluation of the hydrologic parameters of the study area.

The study has determined that recharge to the ground water system relies principally upon seasonal precipitation and enters the subsurface relatively uniformly throughout the study area. Due to a lack of past data collection, no water quality trends could be identified. The primary water right holder in the study area is the City of Westport, which holds sufficient authority for annual qualities of water, but needs to immediately upgrade their authority to extract instantaneous quantities. Finally, the modeling has identified the potential for salt water intrusion in the Westport area, particularly in dry years.

The study concludes that the maximum drought year capability of the North & South Well fields to be approximately 190 million gallons, whereas the average current annual production rate is 217 million gallons. Recommendations are made to develop alternate additional supplies on the Westport Peninsula (50-100 million gallons per year potential) and off of the peninsula near the Roberts Farm test well (estimated 1000 gpm potential).

This study also evaluated existing and future surface activities that have the potential to impact water quality of the underlying aquifers. Several impacts are identified, including storm and surface water, on-site disposal systems, spells, and leaking underground storage tanks. Based on the geology of the soils on the Westport peninsula, programs are recommended to provide protection of the aquifer from surface activities. These include a storm and surface water management program and a wellhead protection program.

I. INTRODUCTION

In 1992 the City of Westport contracted with Consoer Townsend & Associates to provide a groundwater characterization study for the City and surrounding area. Robinson & Noble, Inc. was contracted as a subconsultant to provide a hydrogeologic analysis for the project. The purpose of this project was to define the aquifer under Westport and the South Beach area to determine the amount of available potable water to support the projected growth of the area. This report represents the findings of that hydrogeologic analysis, and evaluation of potential impacts of surface activities on the aquifer.

The City of Westport is located on the south side of the entrance to Grays Harbor on the Washington coast. The City is situated on a peninsula called Point Chehalis, and as such is surrounded on three sides by salt water. The source for all of Westport's potable water is the aquifer underlying the city and the South Beach area. Replenishment of the aquifer is solely through recharge from precipitation. The two principal sources of potential contamination are through percolation of pollutants from surface activities and salt water intrusion through over-pumping of the resource.

The City of Westport, recognizing the vulnerability of the aquifer, applied for, and received a Centennial Clean Water Fund grant from the Washington State Department of Ecology to study and characterize the available water in the aquifer. Grays Harbor County participated in the study by providing a portion of the local share of the matching funds to cover the evaluation of the unincorporated area of South Beach.

This study is the prelude to developing a Groundwater Management Plan to protect the aquifer for the use of the citizens of the city, adjacent unincorporated areas, and those others such as tourists who depend on a high quality, reliable water supply. This study builds the foundation for developing a wellhead protection plan, a surface water management plan, a sewage disposal plan, and other programs to effectively control potential pollution of the city's drinking water source.

The study was divided into nine specific tasks:

- Task 1 Establish Study Area Boundaries
- Task 2 Review Committee
- Task 3 Collection of Hydrogeologic Data
- Task 4 Data Reduction
- Task 5 Data Analysis
- Task 6 Monitor Wells
- Task 7 Groundwater Model
- Task 8 Report of Findings
- Task 9 Project Management

The area studied was from Westhaven in the north to the Pacific County line on the south, and from the Pacific Ocean on the west to the Elk River and the base of the foothills on the east. While the study covered a substantial area, data collection, analysis, and reduction, as well as the location and use of monitoring wells was concentrated within the city limits of Westport. Fifty percent of the study was in the city, 25% covered the area from the city limits to the south boundary of Twin Harbors State Park, and the other 25% covered the remaining unincorporated area south to the Pacific County line. The study included a comprehensive subsurface investigation of hydrogeological conditions, groundwater quality, precipitation, recharge potential, water rights, and water usage. Additionally, surface activities such as population, land use, sewage disposal, and storm water were evaluated as to their potential impacts to the groundwater.

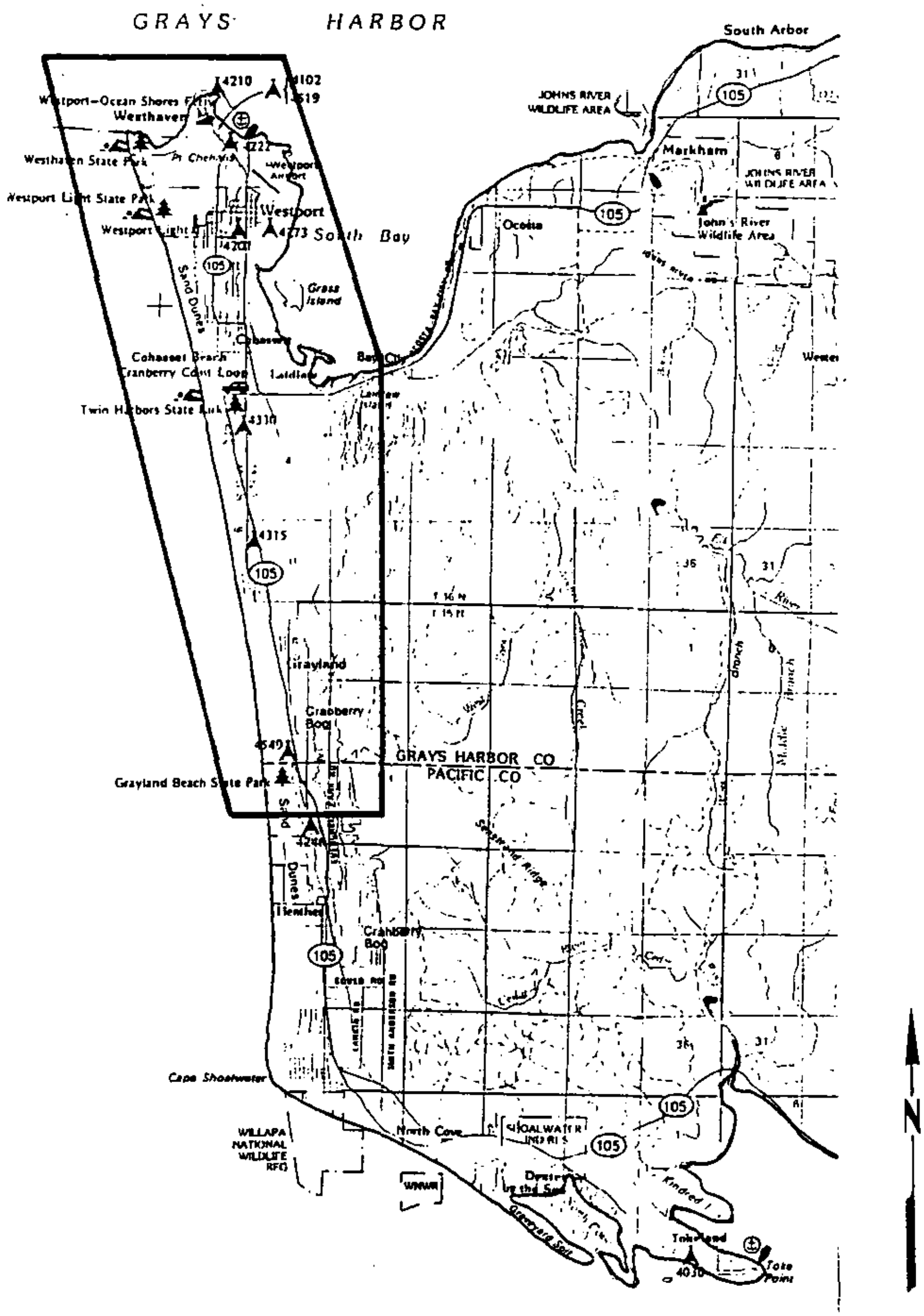
Data on existing facilities were gathered reduced and analyzed. The analysis was divided into four major components: collection and reduction of background data, construction and testing of five new monitoring wells, development of a ground water flow model, and the analysis of collected or generated data to provide a comprehensive assessment of the hydrogeology. The study area boundary extends from the Westport peninsula south to the Grays Harbor County line at Grayland (Figure 1).

Background data was collected from several sources. Hydrogeologic data was compiled from the Department of Ecology (DOE), Robinson & Noble files, and published reports. Westport well field production and water level data was provided by the City. Water quality data was supplied by the Grays Harbor County Department of Human Services, the Department of Health, and the City of Westport. Precipitation data was extracted from NOAA publications. Water right information was obtained from the DOE. Much of the background data was organized and entered into a computerized database.

Five monitoring wells were constructed within the study area. The monitoring wells were drilled between 70 and 110 feet deep. Three are completed in the same aquifer which Westport currently uses for ground water production; two are completed in deeper zones. The wells helped fill data gaps, allowing for the construction of the ground water flow model.

The computer model was constructed for use with the MODFLOW code on a 386 or 486 personal computer. The model represents the synthesis of all known hydrogeologic data on the Westport Peninsula and provides valuable insights into how the hydrogeologic system on the peninsula operates. The model provided an estimate of the safe production limit for the current Westport well fields under drought conditions.

FIGURE 1



BASE MAP TAKEN FROM *WASHINGTON ATLAS & GAZETTEER*

SCALE 1:150,000

ROBINSON & NOBLE, INC.

LOCATION OF WESTPORT STUDY AREA

After the model was completed, the collected and generated data were re-evaluated in conjunction with the modeling results to assess water resource availability in the area. Two major options were identified to increase the water supply for the City: 1) the development of a third well field located between the existing North and South well fields, and 2) the development of a well field on the Roberts Farm.

II. HYDROGEOLOGIC ANALYSIS

2.1 DATA ACQUISITION

The study began with the collection of well information in the region. The Westport well data set comes from three sources: well logs submitted to the Department of Ecology, Robinson & Noble files, and monitoring wells drilled specifically for this study. Well logs were collected from the Department of Ecology for wells in and around Westport, for wells in Grayland and the northernmost portion of Pacific County, and from deep (> 100 feet) wells in the Ocosta/Bay City area across South Bay from Westport. Additional information on City wells, Grays Harbor Water District Wells #1 and #2, and numerous test wells in the area was collected from Robinson & Noble files.

The wells were located on topographic maps to quarter-quarter accuracy or better, when possible. Location accuracy was aided by use of street addresses and aerial photos of the region. Most of these wells are small single domestic or small multiple domestic wells (such as mobile home parks) ranging in depth from 10 to 700 feet. The majority of the wells are between 50 to 150 feet in depth, with a few deeper test and exploration wells, such as the 700-foot deep USGS test well at Twin Harbors State Park. The wells were typically drilled using air-rotary, cable tool, auger, or driven point methods.

The well information was then organized and entered into a computer database. The database is organized to accept information such as: well location, depth, diameter, screen depth and type, any physical or chemical tests made, etc. The database form is based upon information required on the Washington State Department of Ecology Ground Water Data Management Form. The initial database had a total of 138 entries.

A subset of data representing the most reliable information from the Westport, South Beach and north Grayland areas was extracted from the original database to form a secondary database. This secondary, local database contains records on 66 wells and was used extensively during the hydrogeologic study and the numerical model construction. Well locations for the local database are plotted on Figure 2 (in pocket). An index of the database follows as Table 1.

Table 1

DATABASE WELLS

REF NO.	LOCAL NO.	OWNER NAME	WELL NAME
001	16N/11W-18N	WESTPORT	OLD SOUTH WELL 3
002	16N/11W-18N	WESTPORT	OLD SOUTH WELL 2
003	16N/11W-18N	WESTPORT	OLD SOUTH WELL 4
004	16N/11W-18N	WESTPORT	SOUTH WELL 4
005	16N/11W-18N	WESTPORT	SOUTH WELL 1
006	16N/11W-18M	WESTPORT	SOUTH WELL 2
007	16N/11W-18M	WESTPORT	SOUTH WELL 3
009	16N/11W-19F	BEATY, CLIFF	
008	16N/11W-18N	WESTPORT	OLD SOUTH WELL 1
010	16N/11W-19C	OCOSTA SCHOOL DISTRICT	
011	16N/11W-19E	WESTPORT CATHOLIC CHURCH	
012	16N/11W-20E	REYNVAAN	
014	16N/11W-29N	ANDERSON & MIDDLETON CO	ROBERTS FARM TEST
015	16N/11W-30M	HEGG, CLARK	
016	16N/11W-30M	COWHERD	
017	16N/11W-30M	HARPER	
018	16N/11W-30N	ASHBY, VERN	
019	16N/11W-31D	MILLER	
020	16N/11W-31N	BORDEN	
021	16N/11W-31N	ROWLEY	
022	16N/11W-31N	ERHART, LEMOINE	
024	16N/11W-31D	CRAWFORD, DAVE	
025	16N/12W-25J	BARDSLEY, DOROTHY	
026	16N/11W-31F	WHALEN, JIM	
027	16N/11W-31D	BASKETT, RUTH	
028	16N/11W-31	MCLEOD, ROY	
031	16N/11W-31D	CLARK, JOHN	
034	16N/12W-02G	WASHINGTON STATE PARKS	WESTHAVEN ST. PARK
035	16N/12W-01D	UNOCAL BULK PLANT	
036	16N/12W-12A	WESTPORT	NORTH WELL 1

REF NO.	LOCAL NO.	OWNER NAME	WELL NAME
037	16N/12W-12B	WESTPORT	NORTH WELL 3
039	16N/12W-13J	M&C DEVELOPMENT CO	
043	16N/12W-25J	MOORE, CLINTON	
044	16N/12W-25J	ROWE T.W.	
045	16N/12W-25R	GRAYLANDS BEACH WATER CO.	
047	16N/12W-25	AYERS, FRANK	
048	16N/12W-25A	SLENES, ALLEN	
050	15N/11W-06	COOPER, AL	
053	15N/11W-06K	REAMS, A.	
056	15N/11W-07	TINGSTROM, H.	
057	15N/11W-07F	JOHNSON, E. N.	
058	15N/11W-17L	GRAYS HARBOR WD #1	WELL #2
060	15N/11W-17D	LADKE, J.	
061	15N/11W-17L	GRAYS HARBOR WD #1	WELL #1
064	15N/11W-18C	WASHINGTON STATE PARKS	WALTER DANIELS PARK
094	15N/11W-08N	LILLEGAARD, O.G.	
125	16N/12W-12A	WESTPORT	NORTH TEST WELL 1
126	16N/12W-12B	WESTPORT	NORTH TEST WELL 2
127	16N/12W-12B	WESTPORT	NORTH WELL 2
128A	16N/12W-12F	WESTPORT	QC-1, EAST
129A	16N/11W-06N	WESTPORT	QC-2, SOUTH
130	16N/12W-13H	WESTPORT	AUGER TEST 69-1
131	16N/11W-13H	WESTPORT	AUGER TEST 69-2
132	16N/12W-13A	WESTPORT	AUGER TEST 69-3
133	16N/12W-12P	WESTPORT	AUGER TEST 69-4
134	16N/12W-24J	WASHINGTON STATE PARKS	TWIN HARBOR SP TEST
135	16N/11W-18N	WESTPORT	SOUTH FIELD TEST WELL
128B	16N/12W-12F	WESTPORT	QC-1, WEST
129B	16N/11W-06N	WESTPORT	QC-2, NORTH
136	16N/12W-01M	WESTPORT	MONITOR WELL 1
137	16N/11W-07M	WESTPORT	MONITOR WELL 2
138	16N/12W-13L	WESTPORT	MONITOR WELL 3

REF NO.	LOCAL NO.	OWNER NAME	WELL NAME
139	16N/11W-31P	WESTPORT	MONITOR WELL 4
140	15N/11W-07K	WESTPORT	MONITOR WELL 5
141	16N/11W-18N	WESTPORT	SOUTH FIELD OBS WELL
142	16N/11W-18P	PETERSON	

The well log and database information was searched to find complete geologic logs with precise locations for use in constructing cross sections of the sub-surface geology of the area. A north-to-south section extending from the North Well Field to the Grayland Water District #1 wells and five west-to-east cross sections were drafted. The west-to-east sections bisect the North Field, South Field, Twin Harbors State Park, Roberts Farm, and Grayland. Cross section locations are shown on Figure 2 (in the pocket). The subsurface geology indicated by these well logs, along with physical data from pumping tests, was utilized in the construction of the numerical computer model of the peninsula's hydrogeology and aquifer systems.

Precipitation data collected for the area is from the Grayland weather station. According to the NOAA Climatological Data Annual Summary, 40 years of record exist as of 1992. The average annual rainfall for the Westport area is calculated to be 73.5 inches. The data was used, in coordination with surficial geology and land-use information, to determine rates and amounts of annual recharge. This recharge data was utilized in the computer model of the peninsula's hydrogeology.

Water chemistry and bacterial analysis results were collected from Grays Harbor County Health Dept. Inorganic chemistry records are minimal, but regular quarterly bacterial results exist for the North Field Wells No. 1 and 2, the South Field (taken as one sample), and for hook-up samples taken around Westport. These hookups were typically located at the north and south ends of the service area.

Pumpage records for the North and South Fields are available from mid-1982 to 1991 on a monthly total basis, and is tabulated in Appendix 1. Water level data for the North and South Field wells and for various monitoring wells has been collected sporadically since the 1940's. This information is tabulated in Appendix 2.

2.2 STUDY AREA GEOLOGY

The study area consists of a sand-mantled area of active and raised, remnant beaches which extend from the Pacific County line to the northern end of the Westport peninsula. The topography is generally lineal, having been developed by dune action and longshore currents.

The youngest dunes are on the ocean front, with older and more stabilized dunes extending inland. The northern end of the study area is a peninsula separated from the mainland by South Bay of Grays Harbor. The southern end of the study area contains a swale of peat bogs on the east edge which abut the uplands. The uplands are a western extension of the Willapa Hills, but consist of younger geologic deposits than those of the main Willapa Hills province. The younger geologic deposits of the western upland extend beneath the yet younger, sandy materials found at the surface.

There are three principal geologic units. These units are mapped on Figure 3 (in pocket) and are as follows:

> Beach Deposits (map symbol Qb). These are the surface sands including active tidal beach, nearshore dunes, and inland stable dunes. At depth, and especially to the north, the Beach Deposits include coarser sand and gravel that was transported by longshore currents. Some of the Beach Deposits at depth are "muddy" and appear to have been deposited in a slack water environment equivalent to today's Grays Harbor. The major shallow aquifers occur in the Beach Deposits unit.
>
> Alluvium (map symbol Qa). These deposits are limited to the area east of Twin Harbors State Park at the south end of South Bay. They are a slack water fill (alluviation) of the back bay and are the modern equivalent of the "mud" intervals in the Beach Deposit unit.
>
> Satsop Formation (map symbol Qs). This is an early Pleistocene (Ice Age) semiconsolidated sequence of clay with beds of sand and gravel. The name here used is suggested by Foxworthy and Walters (1971) after Newcomb (1946). The Washington State Geologic Map designates the unit as "Quaternary Terrace" which we find difficulty with in a technical sense. The term Satsop should be considered as an informal and general designation for all of the Quaternary age deposits in the Westport area which are not otherwise designated as Beach or Alluvium. Newcomb describes the Satsop as being a Pleistocene-age alluvial deposit, consisting mainly of compact, weathered clays and decomposed sandstone and conglomerates. These coarse deposits occur locally in lenses and often have a reddish, oxidized color.

During this investigation, interpretive cross sections of the subsurface geology were prepared from well logs from Department of Ecology and Robinson & Noble records. Wells were chosen for quality of geologic description and accuracy in location, as described above. These logs are identified in Figures 4 to 9. From the cross sections, a general trend can be seen. In the north-to-south section, a sequence of sand and gravel deposits, coarsening and thickening to the north, overlies finer grained deposits. The upper deposit is designated "Beach" and the lower is "Satsop".

The Satsop Formation occurs as a bench east and south of the Westport peninsula and is exposed in bluffs east of Grayland. The western margin of the bench is wave-cut (Wegner, 1956). The Satsop is also identified in well logs from the Ocosta-Bay City area, on the east side of South Bay. At the Grayland Water District, Wells 1 and 2 penetrate the Satsop from a few feet below ground to full depth of 381 and 397 feet, respectively. The surface of the Satsop slopes downward toward the north, where it is found at a depth of approximately 125 feet at the Westport South Well Field and probably deeper at the North Field where it was not encountered during drilling.

Overlying the Satsop is a series of longshore, dune and back-bay deposits of Recent age. The deposits are typically fine to coarse sands and gravels, with some peat bogs at the surface. The grain size of the sands is finest at the south, where they abut the wave-cut bench of the Satsop. To the north, where the Satsop bench slopes downward, the Recent sands and gravels become more coarse as they form the Westport peninsula and extend into Grays Harbor. Additionally, the thickness of these Beach Deposits increases towards the north.

With respect to water production, wells south of an east-west line extending approximately through the Ocosta School District high school at the south edge of Westport generally penetrate all of the Recent sediments and produce water from zones of sand and gravel within the Satsop. Well depths are typically over 200 feet. Well yields tend to be small to moderate, and water quality is generally good, although elevated iron and manganese concentrations are present at some locations. To the north of this line, the Beach Deposits both thicken and become coarser-grained. Wells of less than 100 feet depth produce large amounts of good quality water, serving Westport's North and South Well Fields. In the database, wells completed in the Beach Deposits are listed as being completed in the "dune aquifer".

WELL SYMBOLS

LITHOLOGIC INTERVAL & IDENTIFIER

▼ *STATIC WATER LEVEL*

SCREENED INTERVAL WITH LOCAL AQUIFER TRANSMISSIVITY IN GPD/FT

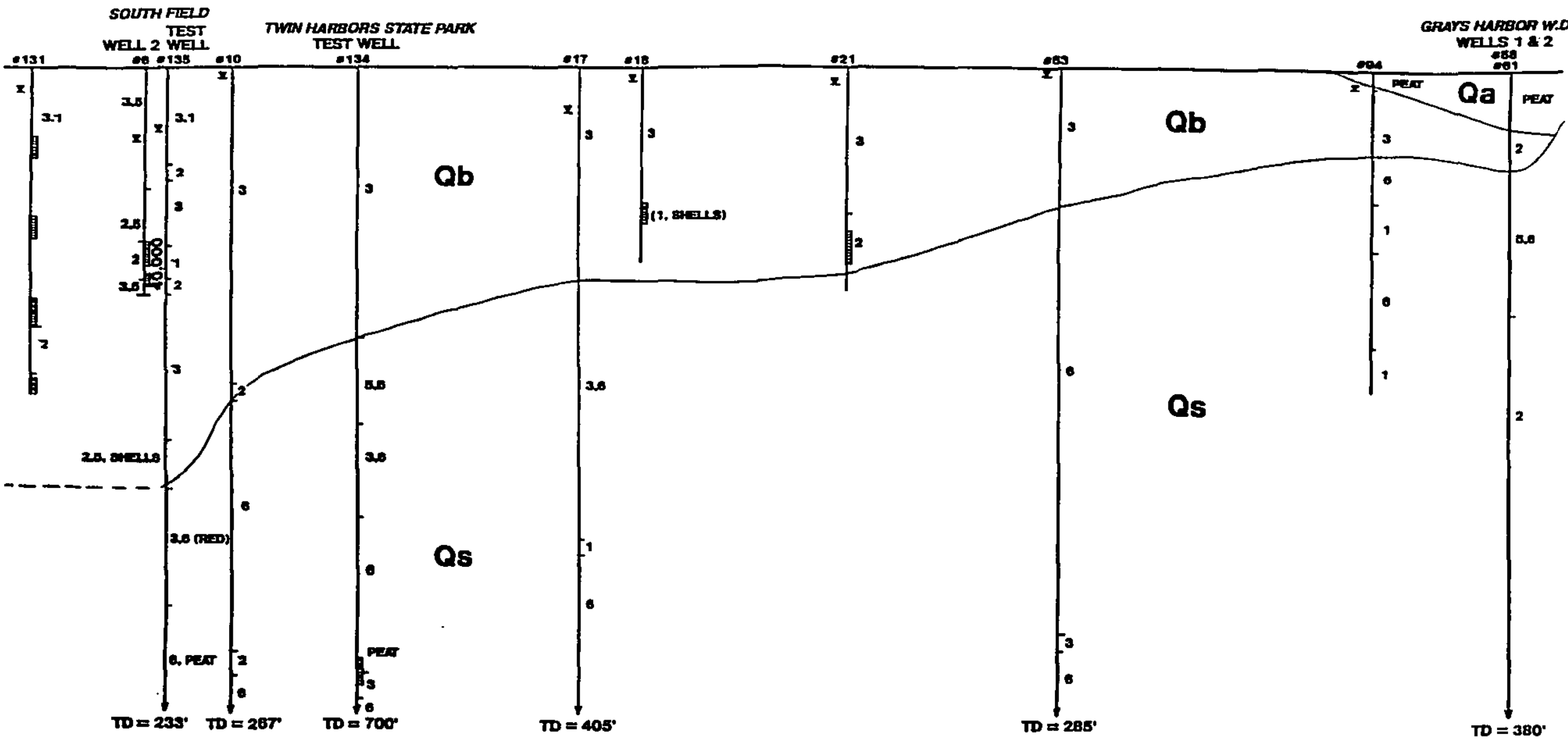
LITHOLOGY

1 GRAVEL
2 SAND & GRAVEL
3 SAND, UNDIFFERENTIATED
3.1 FINE SAND
3.2 MEDIUM SAND
4 GRAVEL WITH MATRIX OF SAND, SILT CLAY
5 SILT
6 CLAY

VERTICAL SCALE 1 INCH = 25 FEET

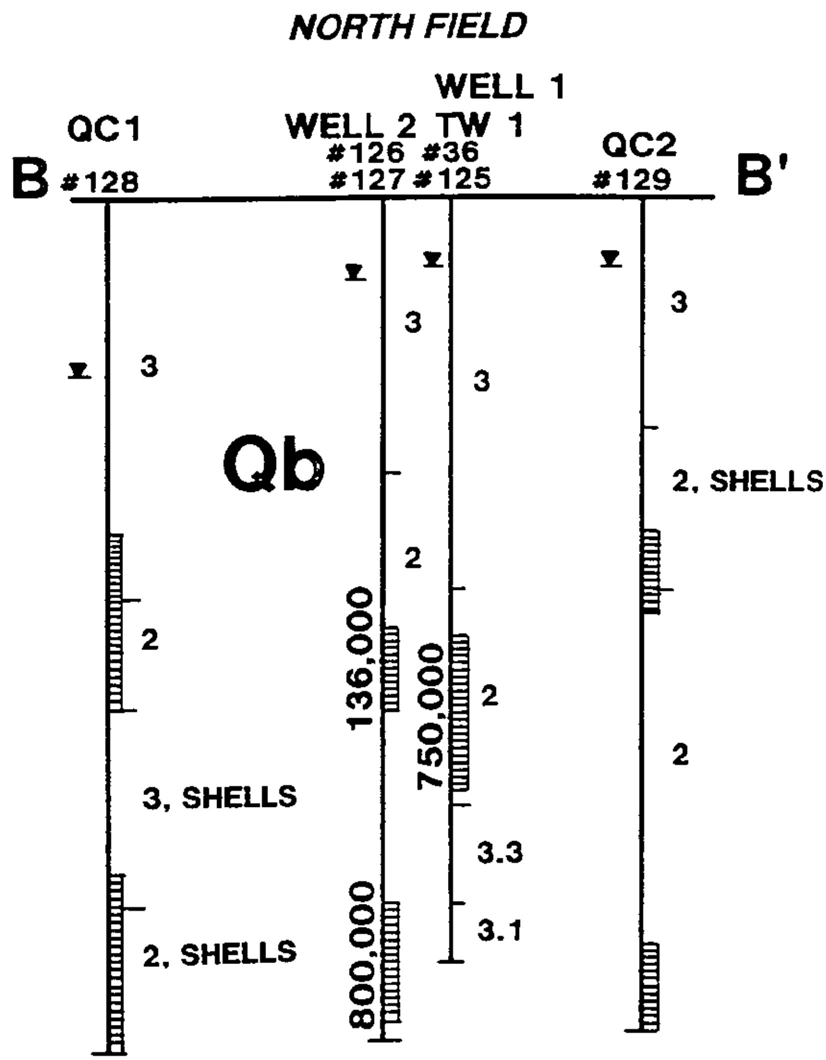
HORIZONTAL SCALE 1 INCH = 2000 FEET

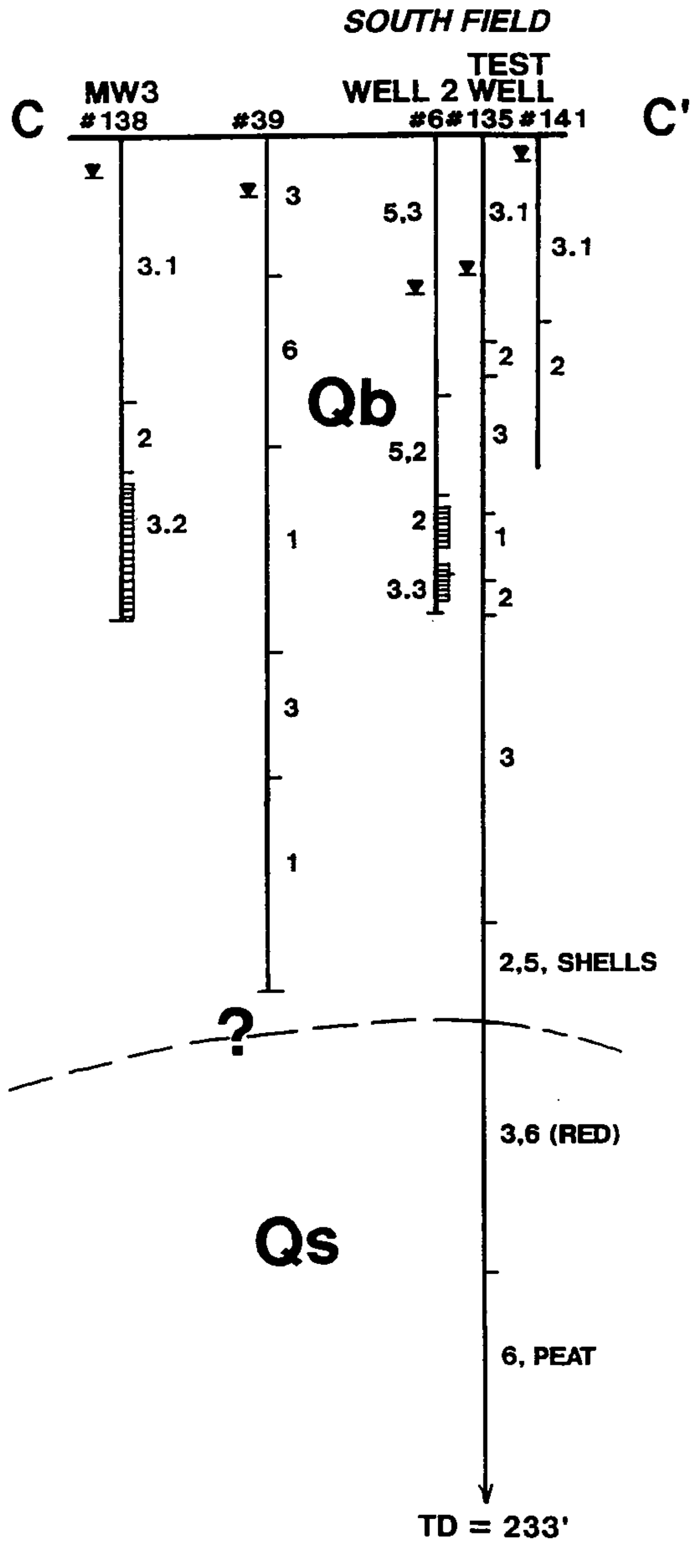
VERTICAL EXAGGERATION = 80

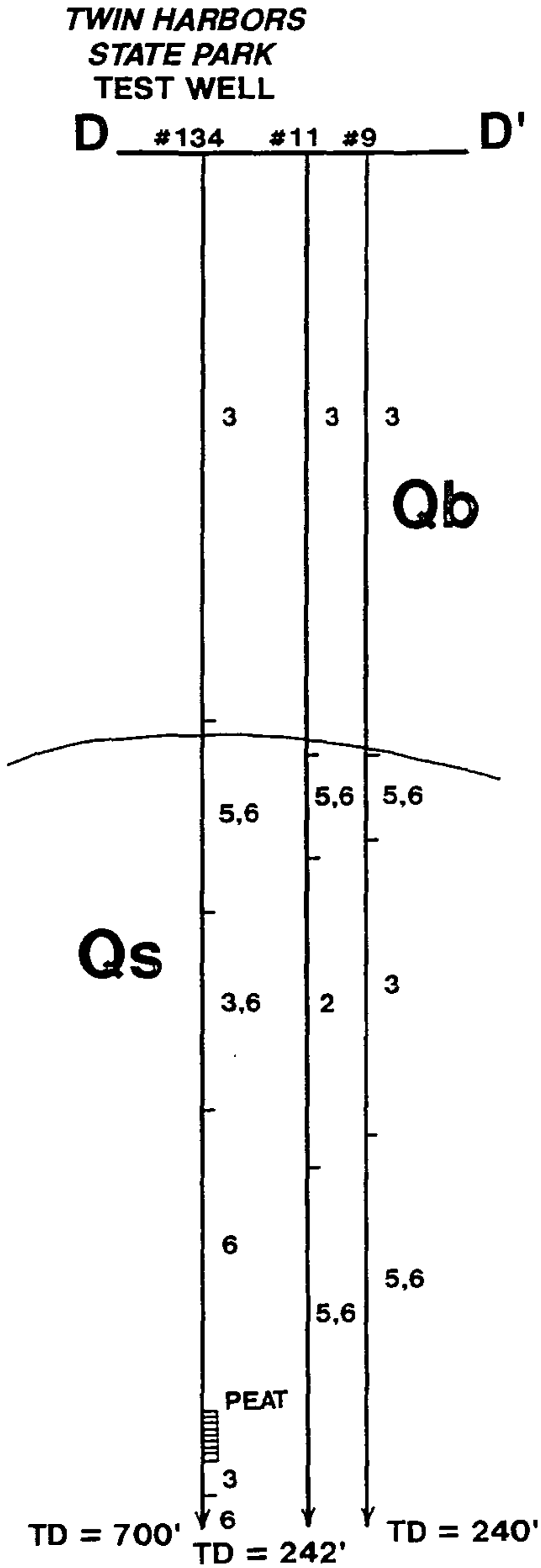


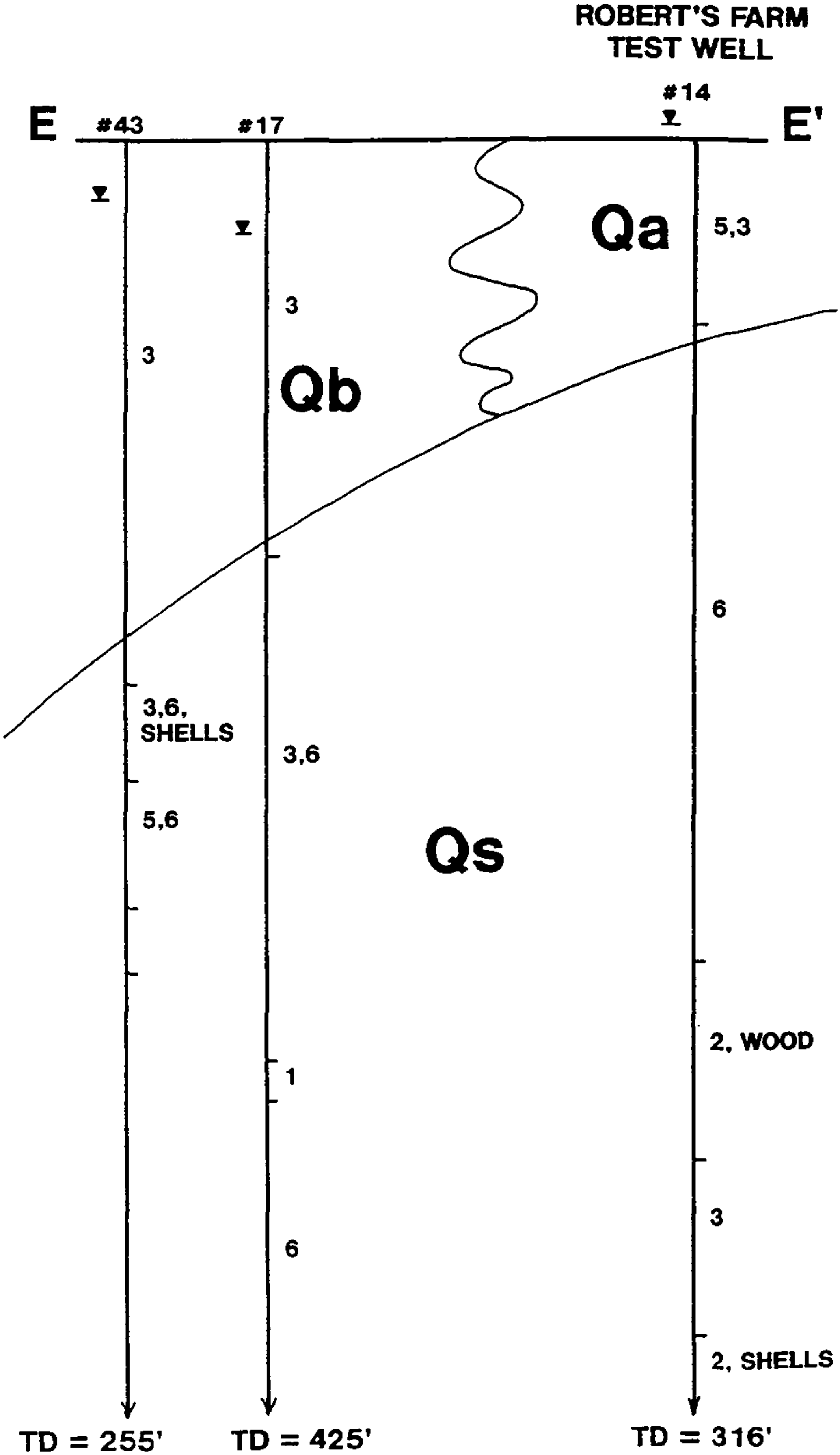
DRAWING NOT TO SCALE

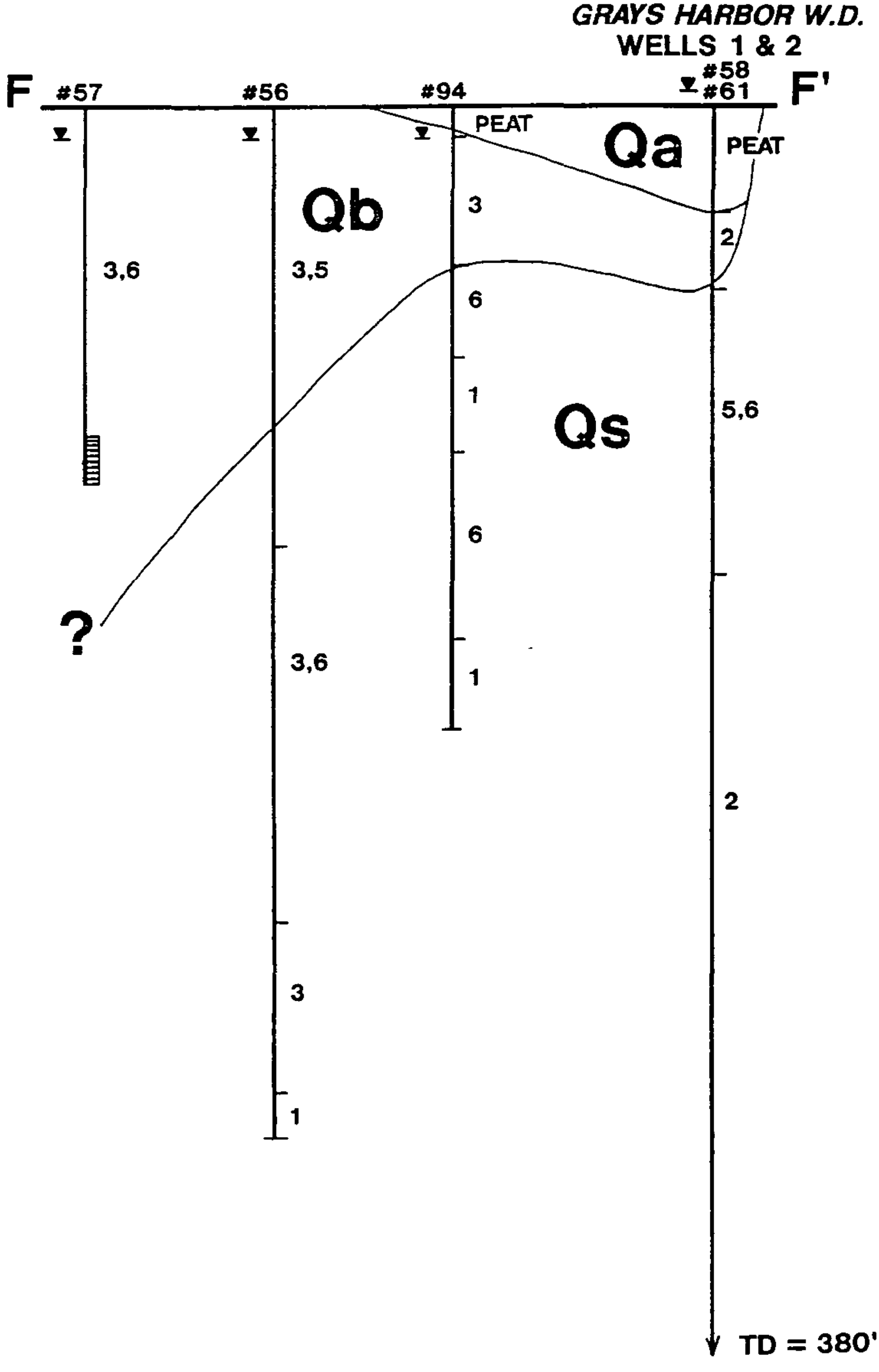
FIGURE 4A


NORTH FIELD
WELL 1
QC1
WELL 2
TW 1
#126
#36
QC2
B
#128
#127
#125
#129
B'
Qb
3
3
3
3
2, SHELLS
2
2
136,000
750,000
2
2
3, SHELLS
3.3
800,000
3.1
2, SHELLS


SOUTH FIELD
TEST
MW3
WELL 2 WELL
C
#138
#39
#6#135#141
C'
3
5,3
3.1
3.1
3.1
6
2
2
Qb
3
2
5,2
3.2
2
1
1
3.3
2
3
3
1
2,5, SHELLS
?
3,6 (RED)
Qs
6, PEAT
TD = 233'


TWIN HARBORS
STATE PARK
TEST WELL
D
#134
#11
#9
D'
3
3
3
Qb
5,6
5,6
5,6
Qs
3,6
2
3
6
5,6
5,6
PEAT
3
6
TD = 700'
TD = 242'
TD = 240'


ROBERT'S FARM
TEST WELL
E
#43
#17
#14
E'
Qa
5,3
3
3
Qb
6
3,6,
SHELLS
3,6
5,6
Qs
2, WOOD
1
3
6
2, SHELLS
TD = 255'
TD = 425'
TD = 316'


GRAYS HARBOR W.D.
WELLS 1 & 2
F
F'
#57
#56
#94
#58
#61
PEAT
PEAT
Qa
Qb
Qs
3
2
3,6
3,5
6
1
5,6
6
?
3,6
1
2
3
1
TD = 380'

2.3 CURRENT PRODUCTION CAPABILITIES

The City of Westport currently has seven production wells located in two well fields. The North Well Field has three wells. Well 1 (Ref. No. 37) was drilled in 1972 and currently produces approximately 47 million gallons (mg) per year (Table 2). Well 2 (Ref. No. 127) was drilled in 1976 and produces approximately 105 mg annually. Well 3 in the North Field was drilled in 1987 and is currently unused.

Table 2

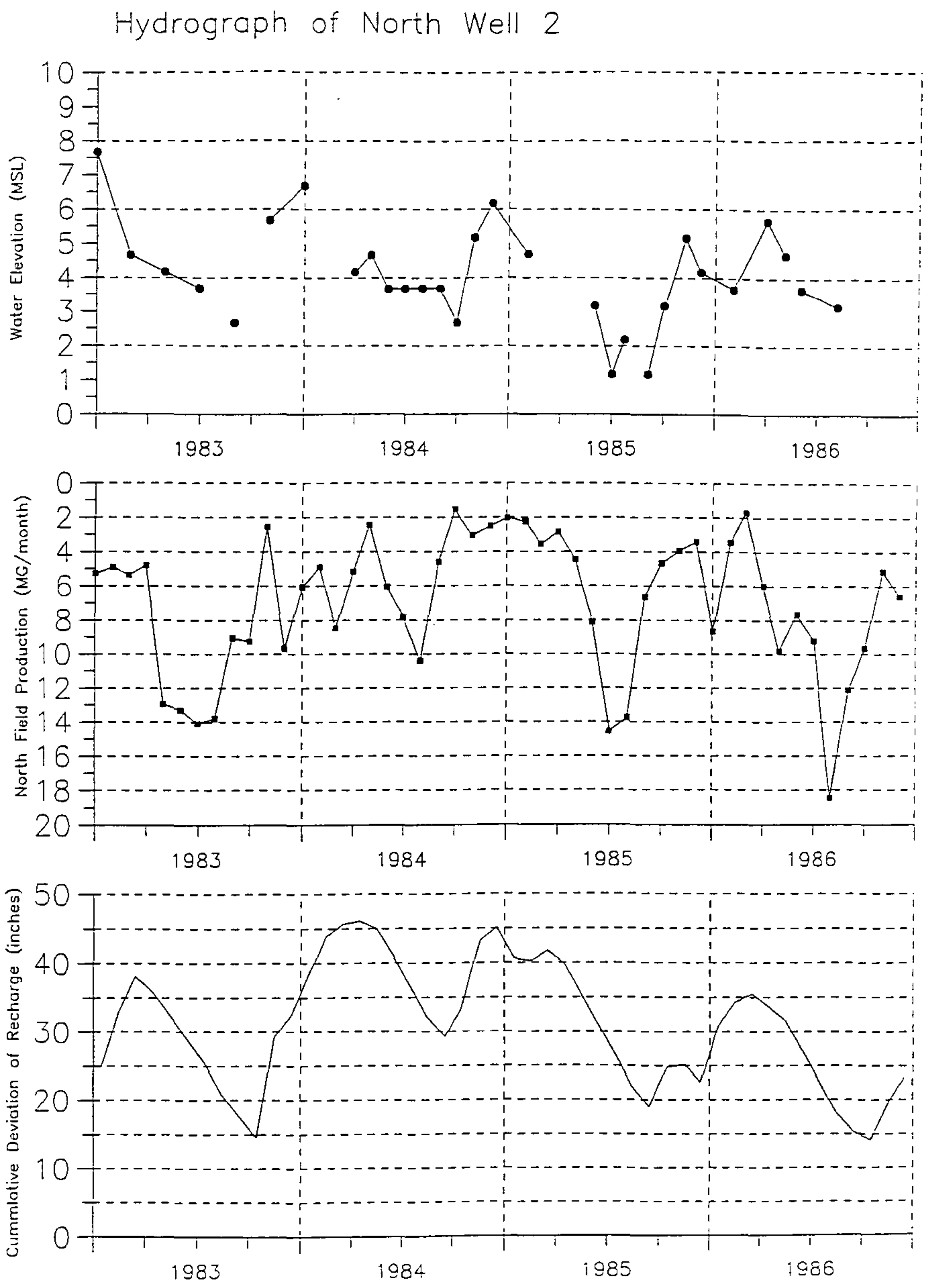
WESTPORT WELL PRODUCTION (mg/yr) 1986 - 1991

	AVERAGE	HIGH	LOW
NORTH 1	47	67	20
NORTH 2	105	155	78
NORTH FIELD TOTAL	152	205	99
SOUTH FIELD TOTAL	65	96	35
SYSTEM TOTAL	212	240	194

The South Well Field has four production wells (Ref. No. 4 - 8). The current wells were all drilled in 1983 and 1984. Each is a second or third generation replacement well for the original four wells, the first three of which were drilled in 1949 and the fourth in 1958. Production from the wells is not metered separately. The average annual production from the field has been approximately 65 mg.

2.4 NORTH FIELD HYDROGEOLOGY

The wells in the North Field produce from a highly transmissive sand and gravel zone within the Beach Deposits. The top of the gravelly zone at the North Field is at approximately 25 feet below sea level, the bottom ranges between 66 to greater than 100 feet below sea level. The zone is topped by a sand unit and bottomed by a fine to silty sand. Geologic logs at QC Well 1 (Ref. No. 128), QC Well 2 (Ref. No. 129), and Monitor Well 2 (Ref. No. 137) indicate the gravelly zone extends east, southwest and southeast of the North Field. The gravelly zone is much less distinct to the northwest of the field as indicated by the Monitor Well 1 (Ref. No. 136) geologic log.


Hydrograph of North Well 2
Water Elevation (MSL)
10
9
8
7
6
5
4
3
2
1
0
1983
1984
1985
1986
North Field Production (MG/month)
0
2
4
6
8
10
12
14
16
18
20
1983
1984
1985
1986
Cummlative Deviation of Recharge (inches)
50
40
30
20
10
0
1983
1984
1985
1986

Aquifer transmissivity calculations at the North Field range between 135,000 and 2,000,000 gpd/ft. The average transmissivity is probably in the 800,000 to 1,000,000 gpd/ft range. The transmissivity is highest near Well 1 and lowest near Well 3. The storage coefficient was calculated to be 0.001. This storage coefficient indicates the aquifer is confined, however, the geologic logs do not indicate a distinct confining layer. The apparent confinement is caused by the lower permeability of the sand overlying the sand and gravel zone in which the wells are completed.

Water levels in the North Field wells have been sporadically measured since 1971 when the first test well in the aquifer was drilled. The water level elevation varies at the North Field from 1 to 8 feet above sea level. Data was sufficient enough between 1983 and 1986 to plot a hydrograph for Well 2 (Figure 10). The data indicates that water levels in the aquifer are a function of both recharge and production.

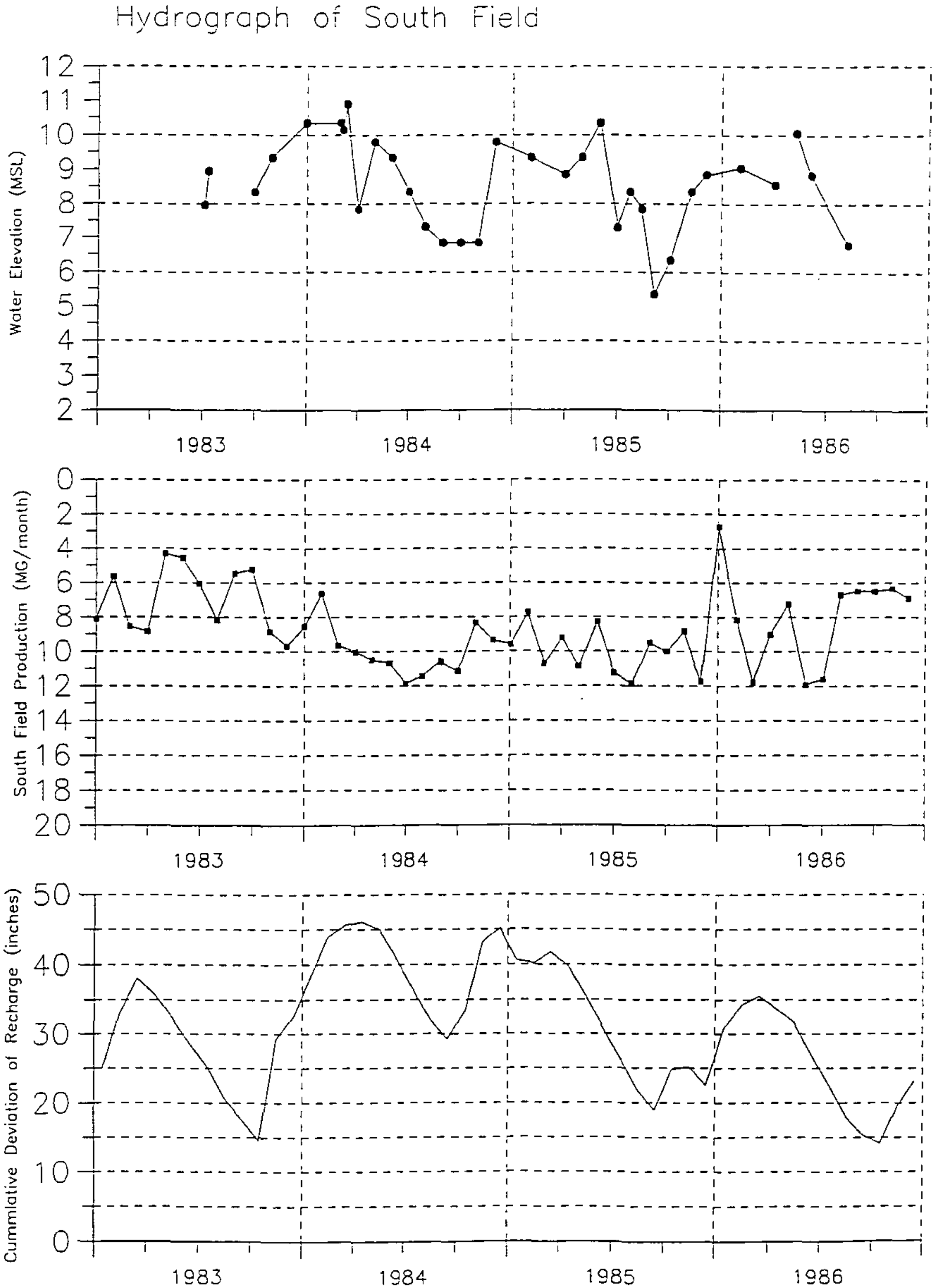
The limited inorganic water quality reports for the North Field wells indicate salt water intrusion has not presently occurred at the field (Appendix 3). However, the numerical model suggests that salt water intrusion at the field is distinctly possible at present-day production rates. Water quality and water level monitoring of Monitor Wells 1 and 2 and QC Wells 1 and 2 should be conducted on a regular basis to forewarn about possible salt water intrusion.

2.5 SOUTH FIELD HYDROGEOLOGY

The wells in the South Field produce from a moderately transmissive sand zone with minor gravel within the Beach Deposits. The top of the production zone is approximately at 25 feet below sea level, with the bottom at approximately 40 feet below sea level. The zone is topped by a silty sand and bottomed by a sand to silty sand. The zone appears to extend westward where a sand and gravel layer was encountered at approximately the same elevation.

The aquifer transmissivity measurements at the field range between 40,000 and 200,000 gpd/ft The average transmissivity is probably closer to the low end of this range. A storage coefficient has not been measured at the field, but pumping tests suggest the aquifer is unconfined and the storage coefficient fairly large.

Water levels were recorded for the field in 1949, and sporadically since 1983. Water levels between 1949 and 1983 were either not recorded or records have been lost. The available records indicate the water level elevation at the field has fluctuated between 4 and 10 feet above sea level. Data between 1983 and 1986 was sufficient to construct a hydrograph of the highest recorded water levels from the four production wells (Figure 11). Analysis of the hydrograph indicates water levels are responding chiefly to recharge and to a lesser extent to production.


Hydrograph of South Field
Water Elevation (MSL)
12
11
10
9
8
7
6
5
4
3
2
1983
1984
1985
1986
South Field Production (MG/month)
0
2
4
6
8
10
12
14
16
18
20
1983
1984
1985
1986
Cummlative Deviation of Recharge (inches)
50
40
30
20
10
0
1983
1984
1985
1986

The aquifer at the well field does not appear to currently be in danger of salt water intrusion. However, the current network of monitoring wells is not adequate to warn of salt water intrusion should it occur. Monitor Well 3 adequately guards the west side of the well field, but a well is needed on the east side. If the original South Field Observation Well (Ref. No. 141), drilled prior to 1949, still exists, it should be incorporated in the monitor well system.

2.6 SOUTH BEACH HYDROGEOLOGY

The top of the Satsop Formation rises toward the south, concurrently, the Beach Deposits become thinner (Figure 4A). Consequently, the importance of aquifers within the Satsop increases' south of the Westport peninsula. On the peninsula, every well in the database is completed in Beach Deposits. Between Twin Harbors State Park and the county line, there are 21 wells in the database; of these, nine are completed in the Satsop formation. South of the county line there are 10 wells in the database, seven of which are completed in the Satsop Formation.

In the South Beach area, the average database well completed in the Beach deposits is 53 feet deep and was tested at 19 gpm. The average database well completed in the Satsop formation is 206 feet deep and was tested at 63 gpm.

The Satsop formation is the major ground water resource in the South Beach area. However, the characteristics of the aquifers in the Satsop formation are highly variable. Three Satsop wells were tested at rates greater than 100 gpm, and three were tested at rates less than 10 gpm. Well completion depths range from approximately 50 feet to 400 feet. Water quality is also highly variable (see water quality section). Aquifer transmissivity has only been calculated at two sites: the Grays Harbor Water District No. 1 wellfield with a transmissivity of 7,000 gpd/ft and the Roberts Farm test well with a transmissivity of 29,000 gpd/ft.

The variability of wells completed in the Satsop is a function of the geologic nature of the formation. Overall, the Satsop is a semiconsolidated sequence of clay-rich deposits with variable beds of sand and gravel. In some places these sand and gravel beds are thick and highly transmissive. At other locations, wells are completed in thin, less productive beds. The Satsop does not contain a single, extensive aquifer zone as is seen in the Beach Deposits of the Westport peninsula.

Data from the South Beach wells is extremely limited and no long term production or water level data is available. As a result, there was no attempt made to construct a computer model to assess the South Beach area hydrogeology. Monitor wells #4 and #5, drilled under this project, are completed in the Satsop formation in the South Beach area. These wells will provide additional data regarding the water level and quality trends of this unit.

2.7 GROUNDWATER RECHARGE

Groundwater recharge within the study area comes from one source: precipitation. Precipitation has been measured at Grayland by the National Weather Service for 40 years as of 1992. However, the Climatological Data Annual Summary for 1992 published by NOAA does not list average precipitation values for Grayland.[1] We compiled the precipitation data (Appendix 4) beginning in 1953 and calculated an average water year (October through September) precipitation of 73.5 inches per year. The average monthly precipitation over the same period is 6.13 inches. We calculated average precipitation values for each month (Table 3) based upon monthly norms at the Aberdeen and Hoquiam weather stations which have 103 and 47 years of record respectively.

Recharge is probably applied fairly uniformly over the area. Aerial photo analysis reveals four major land covers which could affect the amount of precipitation reaching ground water. The highest infiltration rate would result from unvegetated, dune sands where little evapotranspiration or runoff would occur. These areas, however, should have little affect on the overall ground water system because they are limited to a thin strip along the beach. There are two basic vegetated land areas: grass/low brush and denser brush/forest. These make up the vast majority of the peninsula. Infiltration rates would be somewhat different for these areas because of differing evapotranspiration rates. However, infiltration rates should be fairly high for both because of the very permeable soils. The last type, suburban and urban areas, will have less infiltration, but the impervious surfaces probably make up only a few percent or less of the peninsula surface area and therefore have little affect on the ground water system.

---

[1]Departure from normal values are listed for stations with more than 40 years of record; the 1993 summary will list values for Grayland.

Table 3

AVERAGE PRECIPITATION, EVAPOTRANSPIRATION AND RECHARGE VALUES (Inches)

	ESTIMATED AVERAGE PRECIPITATION	ESTIMATED POTENTIAL EVAPOTRANSPIRATION*	ESTIMATED RECHARGE
JAN	11.5	1.15	10.3
FEB	8.6	1.15	7.4
MAR	8.0	1.75	6.3
APR	4.8	2.20	2.6
MAY	3.0	2.80	0.2
JUNE	2.2	3.00	0
JULY	1.2	3.25	0
AUG	1.9	2.80	0
SEPT	3.5	2.20	1.3
OCT	6.7	1.75	4.9
NOV	10.0	1.30	8.7
DEC	12.1	1.15	11.0
ANNUAL	73.5	24.50	52.8**

* From Tracy (1978)
** 53.6 inches using 1953 through 1992 data set rather than estimated monthly averages

Runoff of precipitation does not appear to be a large factor on the peninsula. The topographic maps of the area do not show any major drainages and only three minor ones along South Bay. Significant amounts of runoff would not be expected on the peninsula because of the highly permeable surficial sediments.

Since runoff is not significant and infiltration is fairly uniform, recharge can be considered as solely a factor of precipitation and average evapotranspiration. Monthly potential evapotranspiration was calculated by Tracy (1979) for the Long Beach Peninsula. The evapotranspiration at Westport is probably very similar.

Estimated monthly recharge was calculated by subtracting potential evapotranspiration from the monthly precipitation. These figures were used in the numerical model. The estimated annual recharge based on the above values is 52.8 inches. If the 1953 to 1992 data set is used, the estimated recharge is slightly higher, 53.6 inches.[2]

Figure 12 shows the water year estimated recharge from 1954 through 1992 plotted as a cumulative deviation from the normal recharge. With this method of analysis, surplus recharge years appear as upslopes on the graph and drought years appear as downslopes. The graph reveals a 5-year long relative drought from 1977 through 1981 and another 5-year long drought from 1985 through 1989. Water year 1992 was also a drought year. The data for 1993 is only available through April, but the total estimated recharge thus far is 41.5 inches, 10 inches below the normal for the same time span. Including water year 1993, there have been 12 deficit recharge years in the past 17 years. The actual amount of recharge the dunal aquifer receives is a function of both precipitation and area. The peninsula has an area of approximately 2800 acres (4.4 square miles). During an average water year, 53 inches of infiltrating precipitation could be expected resulting in approximately 12,400 acre-feet of recharge. During a drought year, the total recharge would be substantially less. The drought year simulated in the numerical model had 31.4 inches of infiltrating precipitation[3] for a total of approximately 7500 acre-feet.

These figures are similar to recharge estimates made by others. Wegner (1956) estimated the 4 square mile, beach area near Grayland received 8,000 to 10,000 acre-feet of recharge annually. For Long Beach, Tracy (1978) figured an average maximum possible recharge of 54 inches.

Recharge from sources other than precipitation is insignificant. The fresh-water marshes and several small lakes on the peninsula receive their water from precipitation or from ground water flow, so do not represent a different source of recharge.

On-site sewage disposal systems are probably a small portion of recharge to the ground water system. A typical 3-person home could be expected to deliver an average daily waste-water flow of approximately 150 gallons (Hantzsche and Finnemore, 1992). Most of the peninsula area is sewered. South of the city limits, Twin Harbors State Park, the schools and a trailer park are also on the Westport sewer system, the remaining buildings use on-site disposal systems (Fred Chapman, pers, comm.). Examination of aerial photographs reveals approximately 350 potential residences in this area. At a discharge rate of 150 gpd each, the on-site disposal systems

---

[2]Monthly recharge was estimated by subtracting Tracy's (1979) evapotranspiration values from each month in the data set. The difference between the two figures indicates the estimated monthly precipitation values on Table 3 are slightly low.

[3]The 31.4 inch water year is derived from actual 1985 calendar year precipitation figures. Based on the 40 years of record, a rechrge of 31 inches would be the 8th worst out of 100 years.

Cumulative Deviation of Annual Recharge based upon Precipitation at Grayland

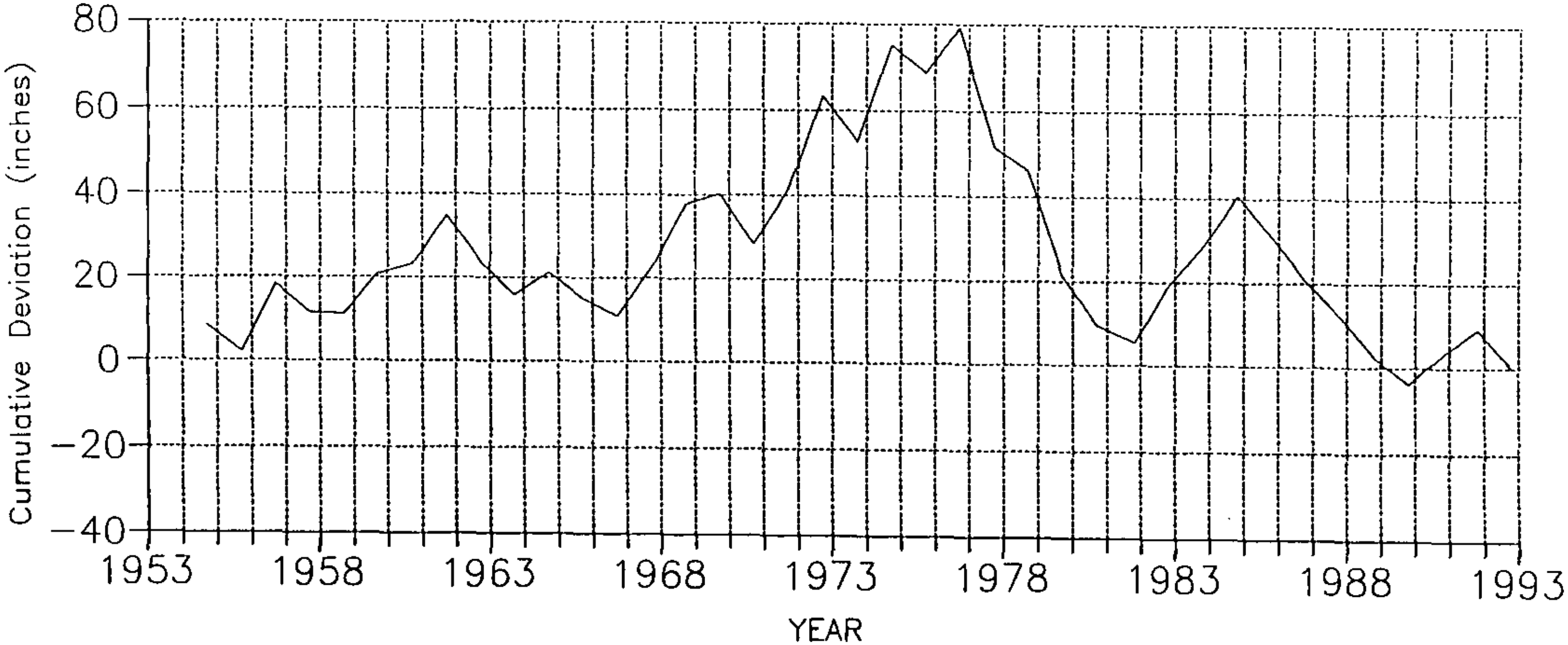


FIGURE 12

represent a total of approximately 60 acre-feet of recharge per year. While notable, this total is not very significant when compared with the total recharge due to precipitation, being equivalent to less than one inch of additional recharge (approximately 1.5%).

2.8 WATER QUALITY

Water quality data within the study area is relatively limited. Inorganic chemistry data is only available on the two City well fields, one Grays Harbor County Water District #1 well (Ref. No. 61), the Surfside Resort Well (Ref. No. 48?), and the Wind Sands Estates Well (not identified). Bacteriological results are available for the above wells (or systems) plus for Twin Harbors State Park and the Sand & Surf Trailer Park. No significant trends in the available data were noted.

Water quality in the Satsop Formation is variable, depending on location and depth. The main problems appear to be with iron and manganese, which can be elevated above allowed maximum contaminant levels (MCL) of 0.3 mg/l for iron and 0.05 mg/l for manganese. Chloride and conductivities, signs of salt water intrusion, do not appear to be problematic (Table 4). However, chloride concentrations and conductivity are, in general, higher than in the dunal aquifer.

Table 4

SATSOP FORMATION WATER QUALITY

Ref No.	Well/Owner	Date	Fe (mg/l)	MN (mg/l)	Cl (mg/l)	Cond. (micromhos/cm)
14	Roberts Farm, 146' depth	3/74	2.0	--	23	--
14	261-271' depth	4/74	0.1	--	20	--
48	Surfside Resort	2/13/89	0.11	0.356	80	450
?*	Wind Sand Estates	6/28/89	0.07	0.128	46	415
61	G.H. Co. WD#1, Well 1	4/8/88	<0.1	<0.01	15	180
61	G.H. Co. WD#1 Well 1	4/4/91	<0.1	<0.01	25	350
140	Westport, MW#5	5/4/93	1.13	0.16	80	490

* Well not identified; based on location, it probably is completed in the Satsop

Inorganic water quality data from the dunal aquifer is limited to periodic samples taken from the Westport system and limited test well data. Data from the North Field wells and South Field wells has been tabulated in Appendix 3. In general, the water quality in the aquifer is good. At the South Field, the manganese concentration is near the MCL, sometimes measuring over it, sometimes under it. The manganese concentration is much lower at the North Field, which has no apparent water quality problems. Iron concentrations were found to be elevated at two 1969 auger test wells north of Cohassett Lake (Ref. Nos. 131 and 132), but is low elsewhere including the North and South Fields, the new monitoring wells (Ref. Nos. 136, 137 and 138), another 1969 auger test well (Ref. No. 133), and at the QC Wells (Ref. Nos. 128 and 129). Chloride and conductivity are not problematic. Chloride concentrations are generally between 15 and 40 mg/l[4], conductivities generally range between 150 and 350 micromhos/cm.

These findings indicate that salt water intrusion is not currently a problem in the study area. A previous investigation by Dion and Sumioka (1984) also failed to detect salt water intrusion on the Westport peninsula.

2.9 WATER RIGHTS

Water rights information was collected from the Department of Ecology for the study area and is tabulated in Appendix 5. On the Westport peninsula (north of and including Twin Harbors State Park), active certificated and permitted water rights have been granted for 1250 gpm instantaneous and 1139.5 acre-feet per year withdrawals. Of these totals, the City owns rights to 950 gpm instantaneous and 1120 acre-feet per year withdrawals (Table 5).

Table 5

CITY OF WESTPORT WATER RIGHTS

Control #	Location	Instantaneous (gpm)	Annual (af)
G2-01002C	South Field	700	1120
G2-00867C	North Well 1	250	200 S
G2-23233C	North Well 2	950 S	1120 S
G2-27060P	North Well 3	500*	403*
Total Non-supplemental		950	1120

S indicates supplemental right.
* indicates right will possibly be supplemental when certified, therefore is not included in total.

[4]Except for measurements made at the South Field in April, 1949 when the chloride concentration was less than 10 mg/l.

The water rights currently held by Westport are adequate to meet future growth in terms of annual withdrawal, but are currently inadequate for instantaneous withdrawal. The current pumping capacity of the North and South Fields combined is 1470 gpm, 520 gpm above the current water right. Since 1986 (exclusive of 1993), the highest annual production has been approximately 240 mg. The current water right is for 1120 acre-feet, or 365 mg. Consequently, the City has current rights to handle an increase in annual production of approximately 52%.

The shortfall in instantaneous right will become even more severe if additional high-use customers, such as the proposed water park and new Washington Crab facility, join the system. The present shortfall can be solved if the Department of Ecology certificates the instantaneous right for North Well 3 (now in permit status) as a primary, rather than supplemental, right. For the Well 3 permit to be perfected to a certificate, the water from the well must be put to beneficial use. Consequently, the well must have a pump installed and be brought on line.

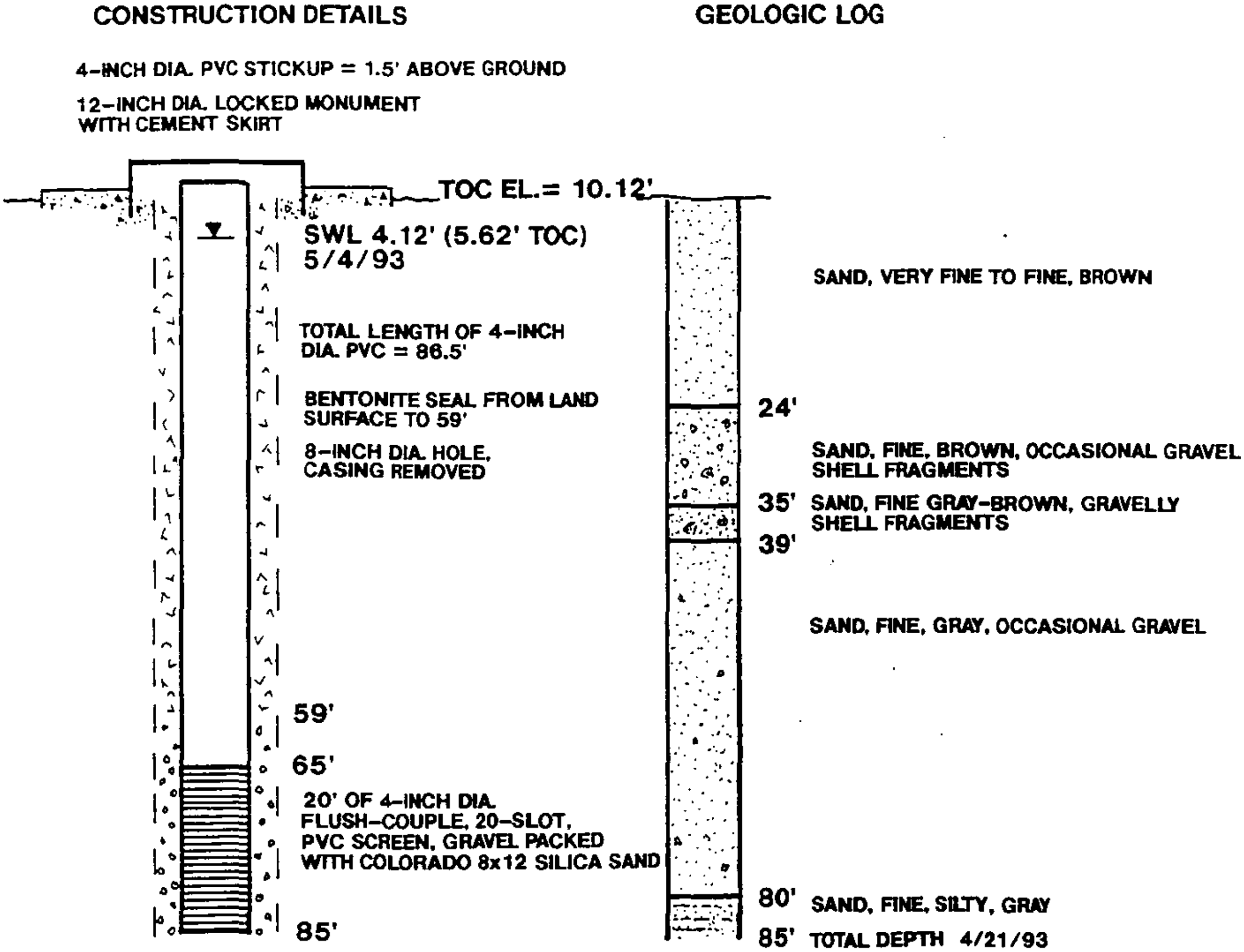
Should an additional well or well field be developed on the peninsula, additional rights, especially instantaneous rights will be required. If a well or wells are developed at Roberts Farm, additional rights will also be needed. These rights should not be made as supplemental to the other rights as the aquifer at Roberts Farm is totally separated from the aquifer on the peninsula.

2.10 CONSTRUCTION OF MONITORING WELLS

Five test/monitoring wells were drilled for the study. Installation of the wells provided additional hydrogeologic data for the study and access points for future ground water level and quality monitoring. The wells were drilled by Hokkaido Drilling and Developing Corp. under the field supervision of Robinson & Noble.

The wells were installed by cable-tool methods utilizing temporary 8-inch steel casing. Upon reaching the target zone, each well was completed with 4-inch diameter, flush-couple, PVC casing. Attached to the bottom of each 4-inch casing is a 20-foot section of pre-slotted PVC screen. The screens were gravel-packed with 8 x 12 sand from Colorado Silica Sand, Inc. Enviroplug medium bentonite chips were placed from top of the sand packs to land surface to provide a continuous surface seal. The 8-inch casing was completely removed from each well during the gravel-pack and surface seal construction process. Each well head is completed with a 12-inch diameter steel monument that is cemented in place with a concrete skirt. The monuments are secured with a City of Westport padlock.

(REF. NO. 136)
WESTPORT - MONITOR WELL 1
T.16 N., R.12 W., SEC. 1M



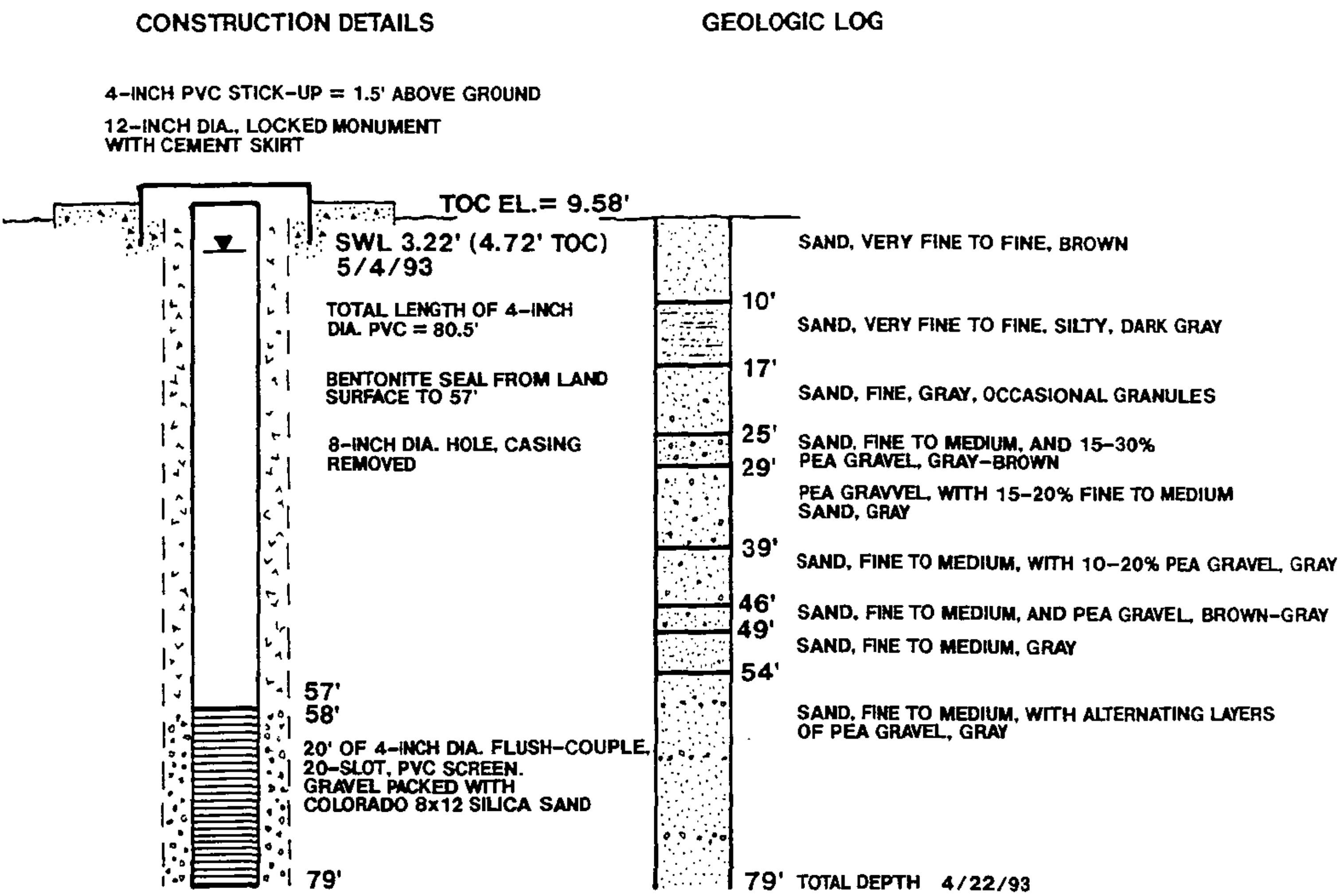
ROBINSON & NOBLE, INC.

FIGURE 14

(REF. NO. 139)

WESTPORT - MONITOR WELL 2

T.16 N., R.11 W., SEC. 7M

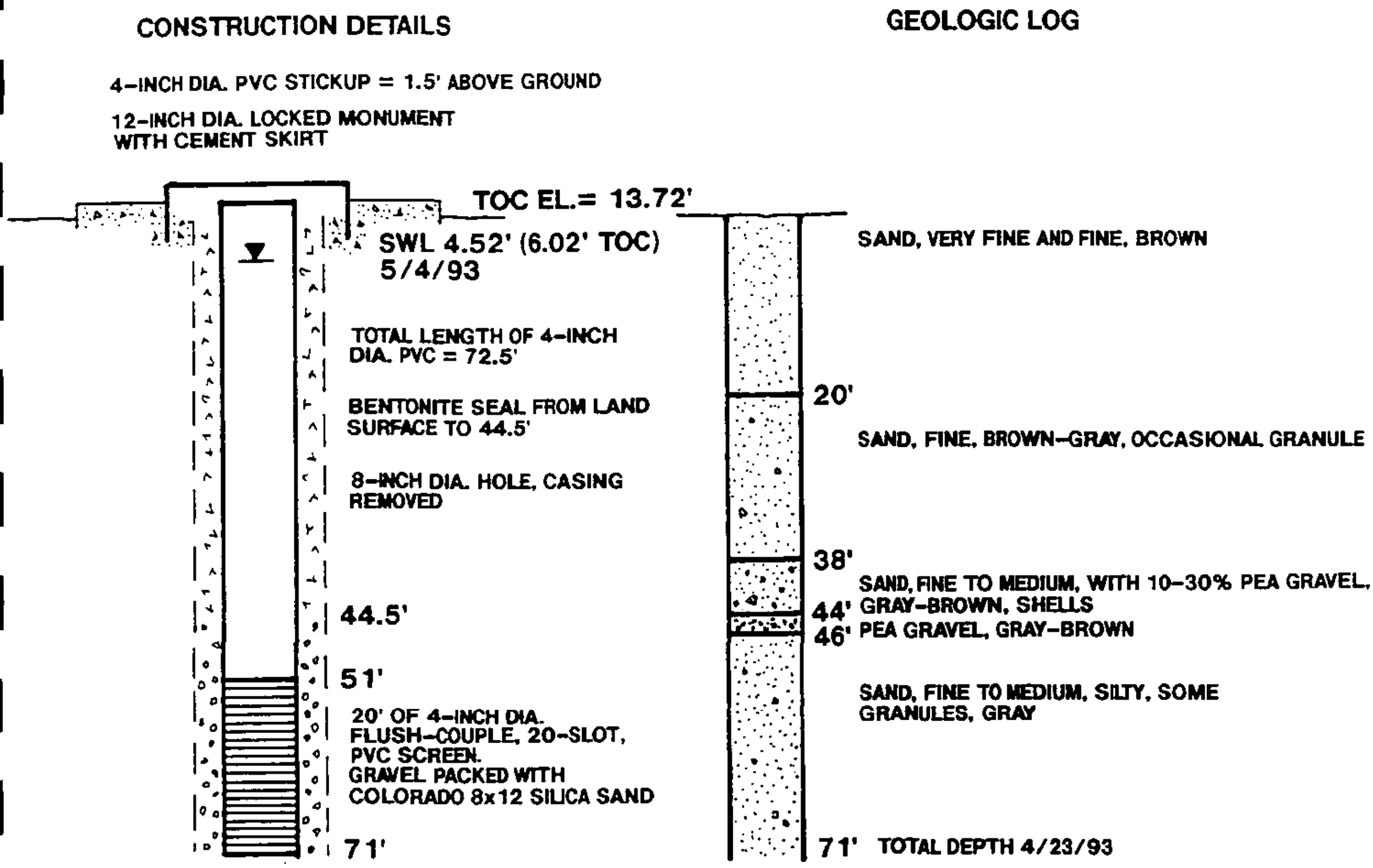


ROBINSON & NOBLE, INC.

(REF. NO. 138)

WESTPORT - MONITOR WELL 3

T.16 N., R.12 W., SEC. 13L



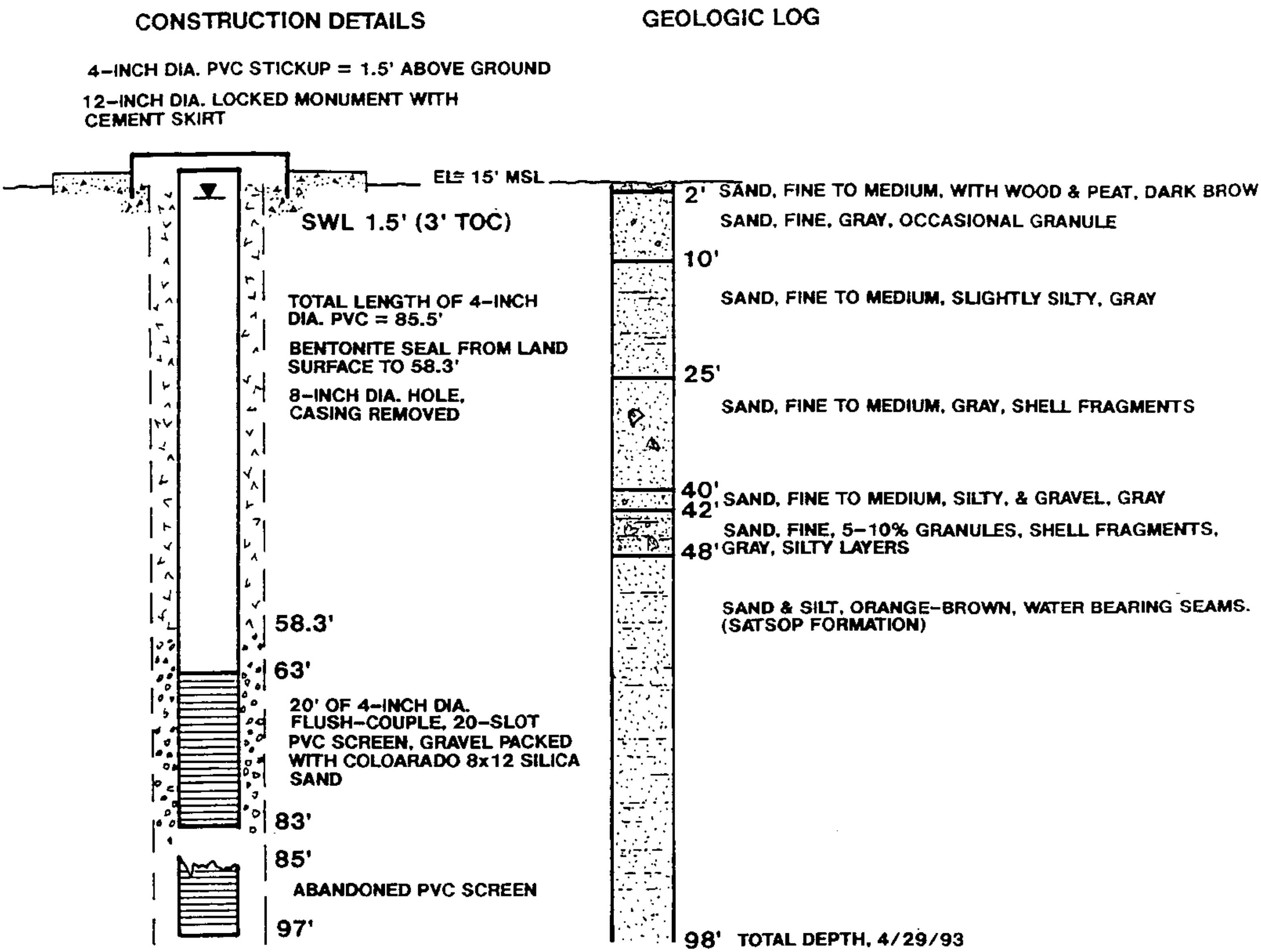
ROBINSON & NOBLE, INC.

FIGURE 17

(REF. NO. 140)

WESTPORT - MONITOR WELL 5

T.15 N., R.11 W., SEC. 7K



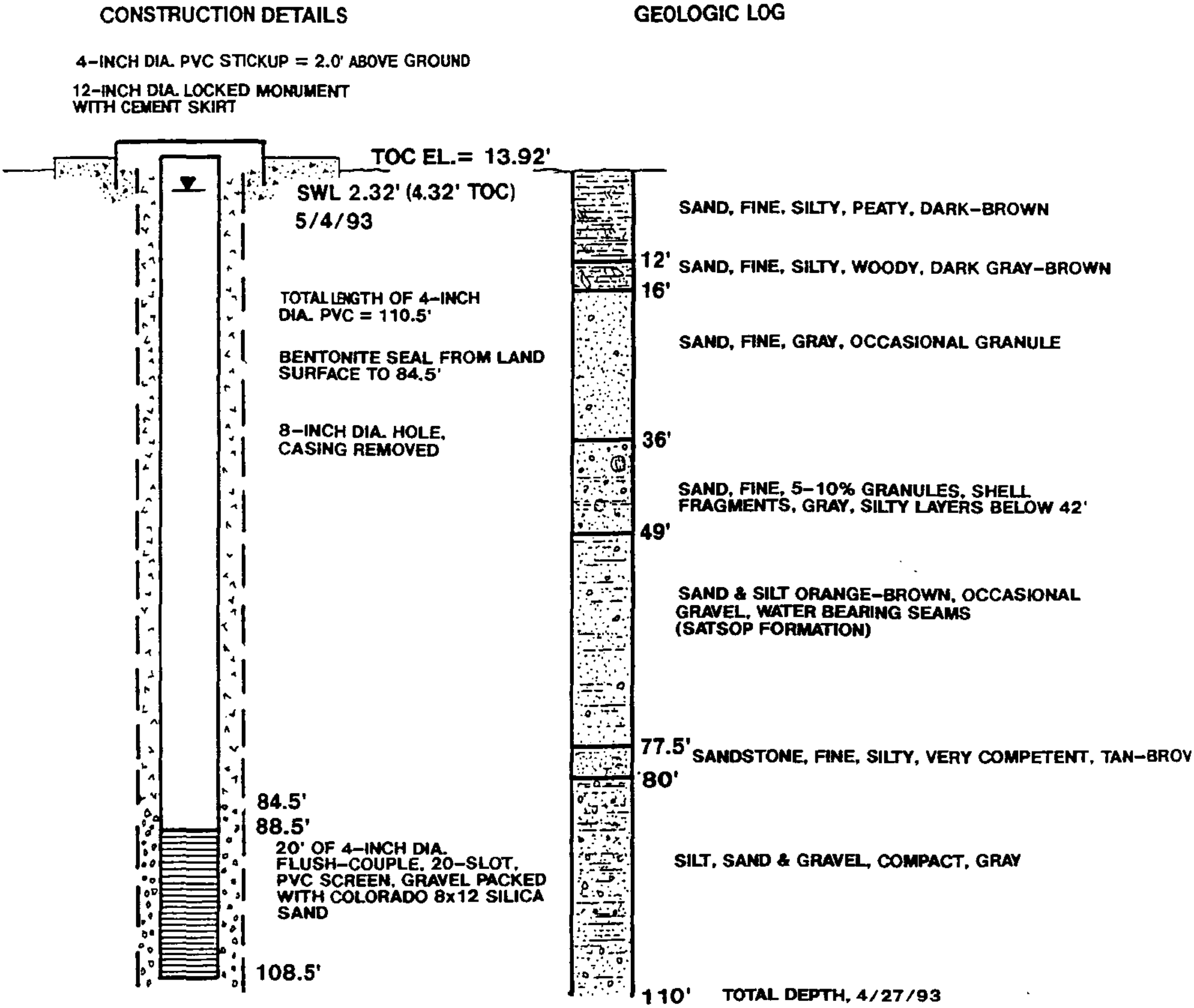
ROBINSON & NOBLE, INC.

FIGURE 16

(REF. NO. 139)

WESTPORT – MONITOR WELL 4

T.16 N., R.11 W., SEC.31P



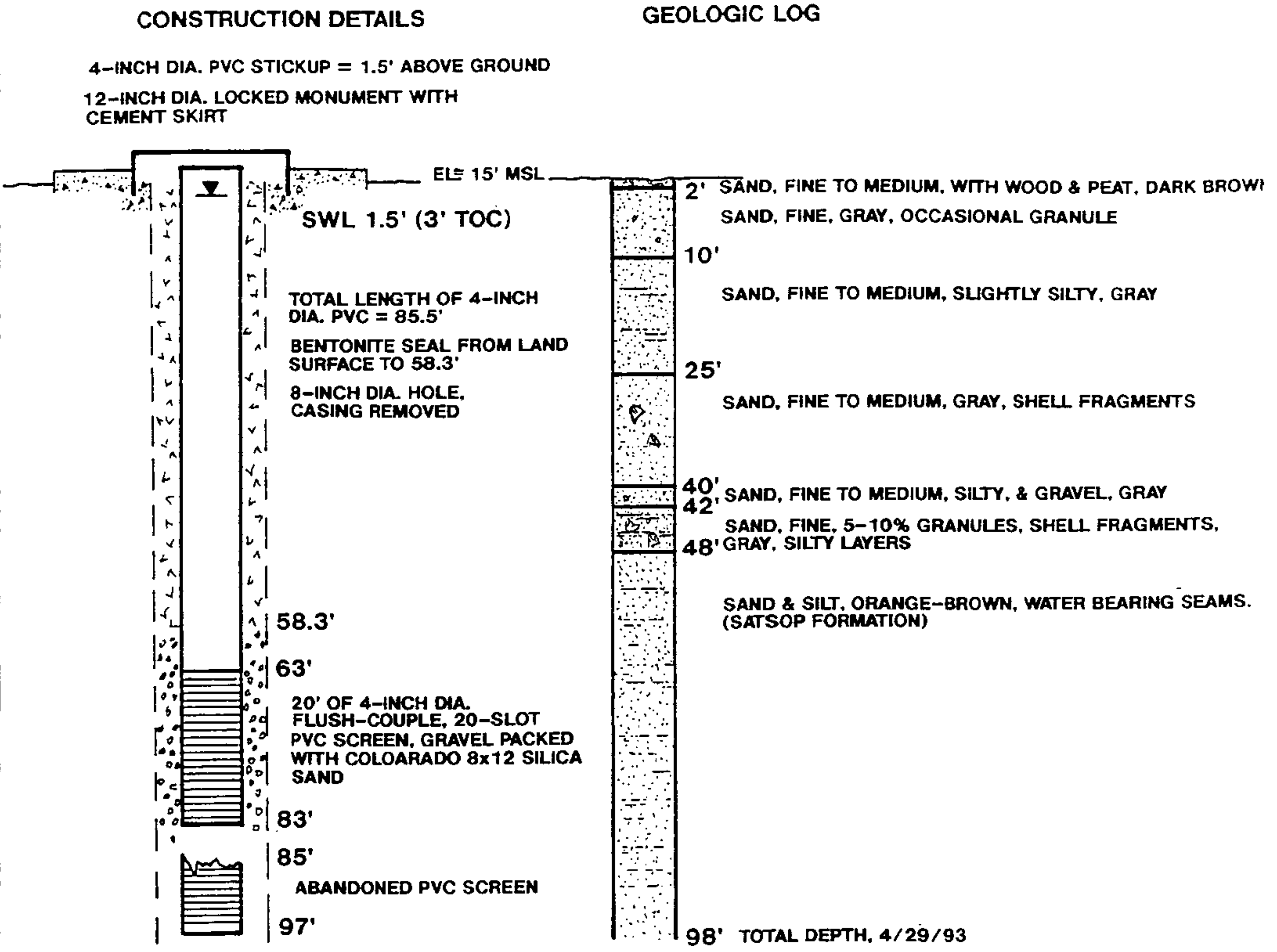
ROBINSON & NOBLE, INC.

FIGURE 17

(REF. NO. 140)

WESTPORT - MONITOR WELL 5

T.15 N., R.11 W., SEC. 7K



ROBINSON & NOBLE, INC.

Table 6 summarizes the basic well data for the monitoring wells. Well construction data, along with a geologic log for each well is presented as Figures 13 - 17. The State of Washington Water Well Reports are attached in the Appendix 6.

Table 6

BASIC MONITORING WELL DATA

Well No.	Location T/R/Sec	MP Elev. (ft,msl)	Depth Drilled (ft)	Screen Setting (ft)	Completion Aquifer	SWL TOC (ft)	Specific Capacity (gpm/ft)
1	T16N/R12W/Sec 1M	10.12	86	65-85	Dune	5.62	8.4
2	T16N/R11W/Sec 7M	9.58	79	59-79	Dune	4.72	22.1
3	T16N/R12W/Sec 13L	13.72	71	51-71	Dune	6.02	4.8
4	T16N/R11W/Sec 31P	13.92	110	88.5-108.5	Satsop	4.32	0.004
5	T15N/R11W/Sec 7K	15*	98	63-83	Satsop	3.0	0.1

*Estimated

The wells were pump developed with a ditch pump. Wells 4 and 5 required additional development and were jetted in addition to the pumping. Though the wells were not formally tested, some basic production data was collected during well development. A water quality sample was also collected during development (except for Well 4) and a partial inorganic chemical analysis was run by Robinson & Noble using Hach field testing equipment. Table 7 lists the results of the partial inorganic analysis.

Table 7

MONITOR WELL WATER QUALITY DATA

WELL #	TURBIDITY UNFILTERED	(NTU) FILTERED	CONDUCTIVITY (umhos/cm)	CHLORIDE (mg/l)	HARDNESS (mg/l as CaCO3)	ALKALINITY (mg/l as CaCO3)	IRON (mg/l)	MANGANESE (mg/l)	REMARKS
1	12	4.5	270	20	10	100	0.04	0.01	---
2	7.2	3.0	355	13	10	150	---	---	tea color
3	5.0	2.5	280	30	10	85	0.03	0.01	---
4	Not run due to insufficient sample								
5	100	35	490	80	20	90	1.13	0.16	---

Review of Tables 6 and 7 reveals the characteristics of the completed monitoring wells and their host aquifers. Wells 1, 2 and 3 are completed in recent gray dunal sands and are quite productive; when developed/pumped at 62, 75 and 61 gpm, the specific capacities were 8.4, 22 and 4.8 gpm/ft of drawdown respectively. On the other hand, Wells 4 and 5 are completed in the Satsop Formation with apparently much poorer production and water quality characteristics. Well 4 is completed in a compact silt, sand and gravel. When Well 4 was developed, it produced almost no water and could not be satisfactorily pumped to obtain a representative water sample. Well 5 is completed in an orange-brown sand and silt, that was competent enough to drill open hole, but did contain water in thin seams. (Well 4 encountered similar orange-brown silt and sand but was completed in underlying materials.) Well 5 produced 2 gpm and had a specific capacity of 0.1 gpm/ft of drawdown.

Wells 1 and 2 can be pumped or bailed as desired to obtain samples for water quality analysis. Pumping or bailing for Well 3 sampling should be kept at a rate of 10 gpm or less because the well tends to produce undesirable quantities of sand at higher rates. Well 4 produces such minute quantities of water that in practical terms it cannot be pumped to collect a water sample. Consequently, samples from Well 4 have to be collected with a bailer. Well 5 can be pumped or bailed at 1 to 2 gpm to collect water quality samples.

2.11 WESTPORT GROUND WATER FLOW MODEL

2.11.1 Conceptual Model

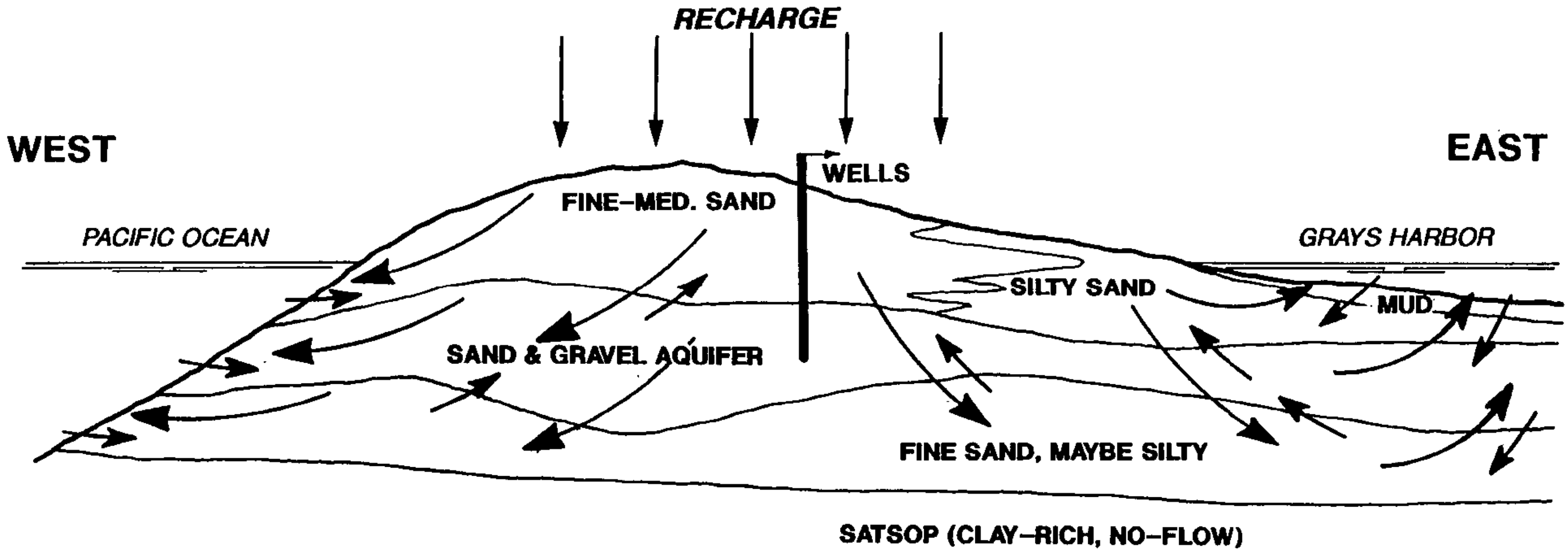
Prior to constructing the computer model, a conceptual model of the Westport peninsula geology was made to aid in construction of the numerical model. The conceptual model synthesizes the information from the geologic logs and cross sections into a generalized representation of the geology affecting the ground water flow system.

The conceptual model (Figure 18) divides the Beach Deposits into three variable thickness subunits, an upper fine to medium sand which may become silty in the east, a deeper sand and gravel subunit in which most wells are completed, and a lowermost, fine sand unit that is silty in places. The underlying Satsop Formation is undifferentiated and has little to no effect on the ground water flow through Beach Deposits.

Ground water flow through the Beach Deposits is generally downward from precipitation recharge, discharging laterally to the Pacific Ocean or Grays Harbor. Water also discharges through wells. Salt water may enter the system from either the Pacific Ocean or Grays Harbor if the freshwater head becomes depressed below sea level.

2.11.2 Modeling Code: MODFLOW

Originally, an analytical ground water flow model was to be constructed for the Westport area. However, a numerical model was constructed because of complications in the geology and the limitations of analytical modeling codes. Analytical codes require uniform values of hydraulic conductivity, aquifer thickness and storage coefficient. But in the Westport area, aquifer



WESTPORT CONCEPTUAL MODEL

FIGURE 18

thickness varies by as much as 100 feet and hydraulic conductivity and storage values vary by several orders of magnitude. A numerical model allows these factors to vary spatially. Additionally, analytical codes require recharge based upon steady-state conditions. However, aquifer recharge at Westport varies with the season. Numerical codes allow for each seasonal variation.

While the hydrology and geology at Westport is complicated enough to make analytical modeling problematic, the hydrogeologic system at Westport is relatively simple which makes numerical modeling of the system relatively easy. Consequently, numerical modeling methods were chosen for the Westport ground water flow model. Unfortunately, numerical models are much more complicated than analytical models, and therefore, the model created here cannot be modified and run by city personnel without extensive specialized training.

There are five numerical methods used for ground water modeling, but finite difference and finite element methods are most commonly used (Anderson and Woessner, 1992). Of these two types of codes, MODFLOW (McDonald and Harbaugh, 1988), a finite difference code, is the most widely used and accepted. Consequently, it was chosen for use in the Westport model. The specific version of MODFLOW used for the study is MODFLOW^{386} v.2.0 supplied by the Geragherty & Miller Modeling Group.

The MODFLOW code consists of a main program and a number of highly independent subroutines called modules. The modules are grouped together into "packages". Each package deals with a single aspect of the simulation. The packages used for the Westport model are listed below.

Table 8

MODFLOW PACKAGES

NAME	ABBREVIATION	DESCRIPTION
Basic	BAS	Handles tasks that are part of the model as a whole including boundaries, initial conditions, time stepping, and results printing.
Block-Centered Flow 2	BCF2	Calculates finite difference equations, specifically flow from cell to cell and into storage. BCF2 allows drying and rewetting of cells.
Well	WELL	Adds terms representing flow to wells.
Recharge	RCH	Adds teams representing arealy distributed recharge
Preconditioned Conjugate Gradient	PCG	Iteratively solves using the Preconditioned Conjugate Gradient method.

2.11.3 Relationship of the Conceptual and Numerical Models

A conceptual model is a representation of a ground water system which amplifies and organizes all major data so that the system can be more readily analyzed. Simplification is necessary because the complete reconstruction of a ground water system is impractical (Anderson and Woessner, 1992). Typically, it is desirable to make a conceptual model as simple as possible, yet retain the ability to produce flow system behavior. Once created, the conceptual model is used as a blueprint to design the numerical model.

2.11.3.1 The Numerical Model Grid

The framework of a numerical model is the model grid. MODFLOW uses a block-centered finite difference grid. The code solves for head at nodes centered in each grid cell. The overall dimensions of the grid are dictated by the conceptual model and the natural hydrologic boundaries of the system.

For the Westport model, the grid consists of three layers representing the three generalized layers in the beach and alluvial deposits above the Satsop Formation. The grid has 110 rows and 60 columns per layer. Variable column and row spacing is allowed with numerical modeling, but a uniform spacing of 200 feet per row and column was used here to keep the model uncomplicated. This spacing gives each cell in the grid an area of 40,000 square feet or approximately 0.92 acres. Cell thickness varies throughout the model (see larger bottom elevations in Appendix 7).

The grid is aligned so that columns trend slightly north northwest - south southeast and rows trend slightly east northeast - west southwest (Figure 19, in pocket). This orientation was chosen to align the model grid with the longitude axis of the Westport peninsula.

2.11.3.2 Boundary Conditions

The selection of proper boundary conditions are critical to a model. Boundary conditions describe the head or the flux at the boundaries of the model domain. Boundaries determine flow patterns for steady-state simulations and greatly influence solutions in transient simulations when the effects of stress reach the boundaries (Anderson and Woessner, 1992).

Two types of hydrologic boundaries exists: physical boundaries, formed by a physical presence (or lack of presence) such as a large body of water or a layer being nonexistent due to erosion, and hydraulic boundaries such as ground water divides and streamlines[5]. Physical boundaries are permanent, hydraulic boundaries can vary with time.

In the Westport model both physical and hydraulic boundaries are simulated. The ocean, Grays Harbor and South Bay represent physical boundaries and form the western, northern and eastern boundaries of the modeled domain. The southern boundary is a hydraulic boundary; a streamline in which flow is tangent to the row direction either westerly toward the ocean or easterly toward South Bay.

In the model, the ocean, Grays Harbor and South Bay are represented by specified head boundaries, a boundary with a defined head value which does not change during the simulation. Here, constant head cells assigned a head of sea level are used to represent these boundaries. When the model runs, water is allowed to flow in and out of these cells at will, as long as the head remains at sea level.

The streamline boundary at the southern end of the modeled domain is represented by the edge of the model grid, in essence a specified flow boundary for which no-flow is allowed to cross The base of the model also is a no-flow boundary, leakage is not allowed through the bottom. While this is not strictly true, water does leak between the beach and alluvial deposits and the Satsop Formation, an impermeable boundary is justified when there are two orders of magnitude difference between the bottom model layer and the materials beneath it (Anderson and Woessner, 1992). This is undoubtedly the case between the sand in layer 3 and the clay-rich Satsop Formation.

Wells also form specified flow boundaries. Well cells are assigned a constant flux during specified times (stress periods) of the simulation.

The boundary conditions define and control the flow system. Water is only allowed to enter the model as recharge or from constant head cells (simulating salt water intrusion). Water can only exit the model at wells or constant head cells.

2.11.3.3 Aquifer Parameters

Every active cell in the model needs to have three to five aquifer parameters assigned to it (Table 9). These parameters need consistent units of length and time for MODFLOW to run properly. The units of feet and days were chosen for the Westport model. The aquifer parameters values at each cell are listed in Appendix 7.

---

[5]A line of ground water flow along which the velocity vector is tangent to the line at every point, i.e. a line which is always in the direction of flow.

Table 9

AQUIFER PARAMETERS

PARAMETER	UNITS	WHERE ASSIGNED
Hydraulic Conductivity	ft/day	All cells
Vertical Permeability	ft/day	All cells except layer 3
Storage	a dimensionless ratio	All cells
Bottom Elevation	ft	All cells
Recharge	ft/day	Layer 1 cells

At most cells in the model, the parameters were estimated based upon well logs and pump test data. Data was sparse enough that statistically based estimation methods were deemed less reliable than basing parameter assignments on hydrogeologic judgement. Each well in the database within the modeled domain was examined for geologic logs, pump test data, and/or other well performance data (such as specific capacity data). From this data, estimates of each parameter (except recharge) for each layer were made at each well location. These estimates were plotted on a map and parameter zones drawn based upon knowledge of the local hydrogeology.

Hydraulic Conductivity. Hydraulic conductivity was estimated at every well site which had a geologic log and available pump test data. This included only seven well sites, the four Westport South Field wells and the three Westport North Wells. At these sites, the pump test data was only valid for layer 2, so hydraulic conductivities for the other layers at the sites were based upon lithologic descriptions. Hydraulic conductivities at other well sites were estimated based upon specific capacity information or upon lithologic description. Initial hydraulic conductivity values in the model were modified, especially in layer 2, during model calibration. Values range from 0.01 to 1000 ft/day.

Vertical Permeability. Vertical permeability or leakance was estimated at every well site for which hydraulic conductivity was calculated or estimated. Vertical permeabilities were estimated by multiplying the hydraulic conductivity by an estimated vertical to horizontal ratio. The ratios were estimated based upon hydrogeologic knowledge and lithologic details. Initial values of vertical permeability were modified slightly during the calibration.

Storage. Field generated storage coefficients were only available at the North Field, so storage values were estimated at every other location. However, the geology of the area is such that the aquifer is mostly unconfined. This simplified the storage estimation process by limiting the values of storage. Initial values of storage were 0.001 around the North Field and 0.1 elsewhere. During the verification process, storage values were modified to be either 0.1 or 0.2 depending on location.

Bottom Elevation. Bottom elevations were assigned based upon geologic log interpretation and knowledge of local geology. Layer assignment on the geologic logs was somewhat subjective because differences between the layers at many locations are subtle. No northern peninsula wells and most southern wells did not extend downward into the Satsop Formation, so the bottom of layer 3 was very subjective. The bottom elevations were not changed during the calibration or verification process except for a minor change in the northern half of layer 3. Bottom elevations in the model for layer 1 range from -10 to -30 feet MSL. For layer 2, the bottom elevations range from -20 to -90 feet MSL, and for layer 3, from -100 to -120 feet MSL.

Recharge. Recharge is only active in layer 1. To avoid too complex a model, recharge is set to one value over the entire model domain, although the value changed with time.

For the intimal calibration runs, recharge was based upon an estimated average value. But after several runs the recharge values were better defined. For the improved definition, recharge values were based upon the average monthly precipitation at Grayland. Potential evapotranspiration values (Tracy, 1978) were subtracted from the monthly recharge values (runoff was assumed to be insignificant). Monthly data was summed to give quarterly values, which was then used for the four stress periods during later calibration runs (Table 10). For the verification runs, actual monthly precipitation values were used rather than average values.

Table 10

QUARTERLY AVERAGE RECHARGE

Quarter	Total Precipitation (inches)	Total Recharge, (inches,)
January - March	28.1	24.0
April - June	10.0	2.8
July - September	6.6	1.3
October - December	28.8	24.6
Total	73.5	52.7

2.11.4 Calibration

The purpose of calibration is to establish that a model can simulate actual field-measured aquifer head levels. Once the boundary conditions and aquifer parameters were assigned, calibration began. The initial calibration used a standard trial-and-error methodology. The procedure involved executing the model, performing an error analysis by comparing results to field-based target data, determining and involving necessary adjustments to aquifer parameters and/or boundary conditions, and re-executing the model. For the initial calibration, thirteen runs were made with each run having four stress periods representing the seasonal recharge for a single year. A secondary calibration was then made using 20 stress periods, representing a five year period. The secondary calibration used 10 runs.

The calibration target heads were based upon the water level database (Appendix 2). Targets were selected to represent a seasonally high, dynamic steady-state, pre-stress condition.[6] Water levels selected were measured during winter or spring, or were manipulated to better represent a winter or spring condition (Table 11). Thirteen targets were selected, eleven in layer 2 and two in layer 3.

---

[6]This condition is dynamic due to seasonally changes in recharge.

Table 11

CALIBRATION TARGETS

Reference No.	Well	Target (ft,msl)	Notes
Layer 2			
4	South Well 4	10.4	Highest recorded water level @ well; several dates
5	South Well 1	10.9	Highest recorded water level @ well; 3/12/84
36	North Well 1	8.4	Highest recorded water level @ well; 1/17/72
127	North Well 2	7.7	Highest recorded water level @ well, 1/73
128A	QC-1, east	6.7	Based on 12/76 data, 1' lower than #127
129A	QC-2, south	5.7	Based on 12/76 data, 2' lower than #127
134	Twin Harbors	8.1	Only recorded water level for 7/30, added 1'
136	MW-1	4.5	Highest recorded water level @ well, 5/4/93
137	MW-2	4.9	Highest recorded water level @ well, 5/4/93
138	MW-3	7.7	Highest recorded water level @ well, 5/4/93
142	Peterson	7.8	Highest recorded water level @ well, 3/1/49
Layer 3			
128B	QC-1, west	5.2	Water Level for 128A minus average difference between piezos
129B	QC-2, north	5.6	Water level for 129B minus average difference between piezos

The calibration was checked at the end of each simulation run by inputting the MODFLOW output into a program called CALSTATS[7], which compares the modeled heads with the calibration targets. CALSTATS computes the residual at each target then computes various statistics based upon the residuals. In this case, the model was calibrated by trying to minimize the absolute residual mean, also called the mean absolute error (MAE), and the residual sum of squares (RSS). The MAE is the average of the absolute values of the differences between the targets and the simulated heads. The residual sum of squares is the sum of the squared differences between the targets and the simulated heads.

For the initial calibration the MAE was reduced from 3.18 to 0.53 feet (Figure 20). The RSS was reduced from 180.2 to 4.5 feet. However, when the final initial calibration run was extended to a 5-year simulated period, the MAE increased to 0.84 feet and the RSS increased to 16.7 feet. This result indicated the simulation had not reached a steady-state condition. The simulation was rerun for periods of 2, 3, 4 and 5 years. Results indicated the simulation approached a steady-state condition after four years. Therefore, the secondary calibration was accomplished with a 5-year period, divided into twenty seasonal stress periods. At the end of the calibration process all simulated heads were within 1 foot of the target heads (Figure 21) with a MAE of 0.34 feet (Figure 20) and a RSS of 2.6 feet.

Many changes from the initially assigned aquifer parameters were made during the calibration process. However, most changes were relatively minor and progressively lead to calibration. The major changes made include: 1) changing from average annual recharge to average quarterly recharge, 2) adding constant head cells to the South Bay area in layer 2 and 3,) the progressive widening of a relatively lower hydraulic conductivity zone across the central portion of the peninsula extending from east of the South Field northwesterly toward Monitor Well 3 and QC-1.

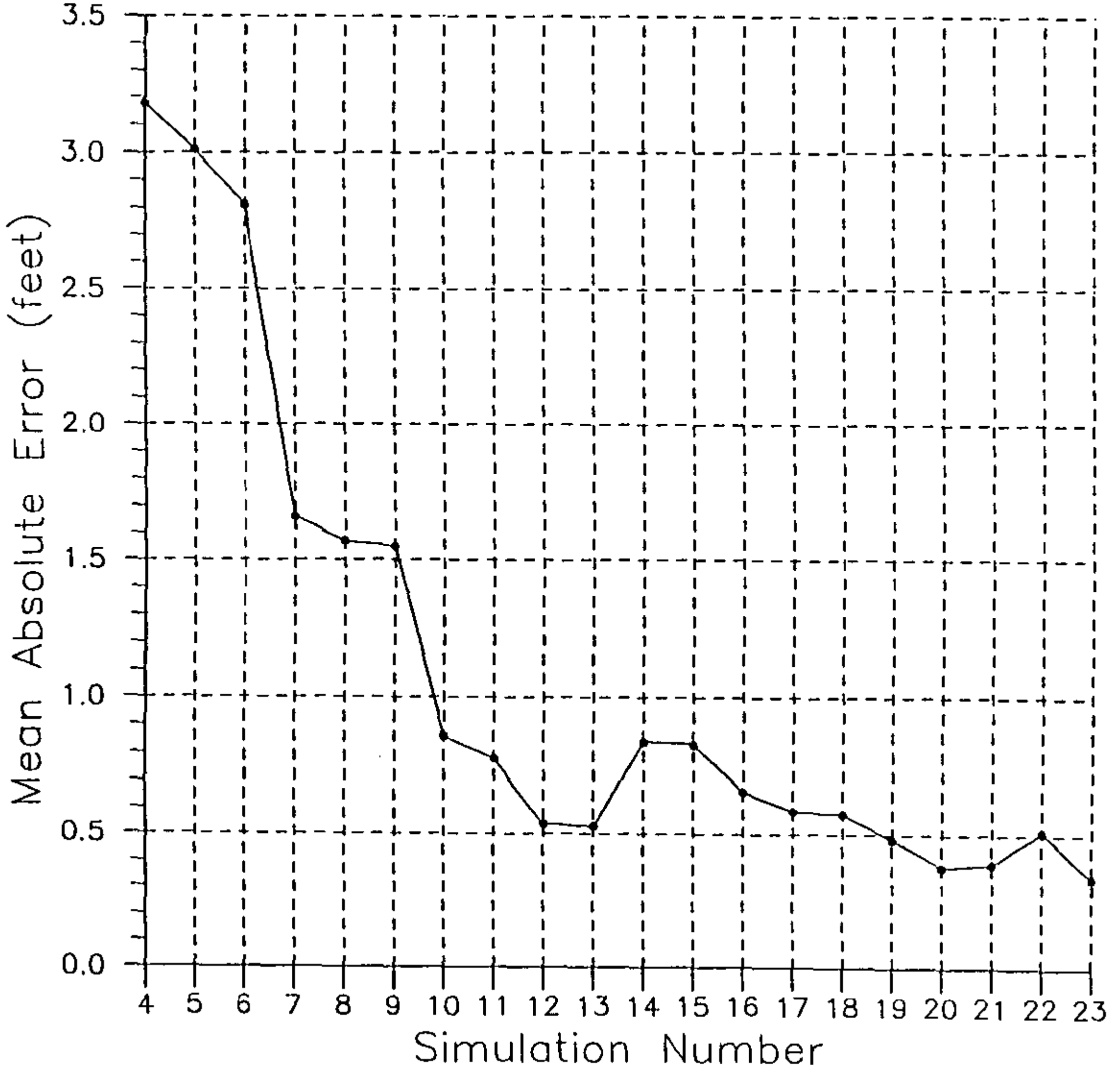
2.11.5 Verification

Model verification gives a greater confidence in a model by using a set of calibrated data (production and recharge data) to reproduce a second known set of head values. If calibration is consider a snapshot, verification is a motion picture. The verification goal was to reproduce the North Well 2 and the South Field hydrographs from January, 1983 through June, 1986. These hydrographs represent the best, continuous water level data subsets in the water level data base (Appendix 2). Four verification runs were made. The first three used fourteen quarterly stress periods. The final verification run used forty-two monthly stress periods. Each stress period used unique values for recharge and well production as listed in Appendix 8.

---

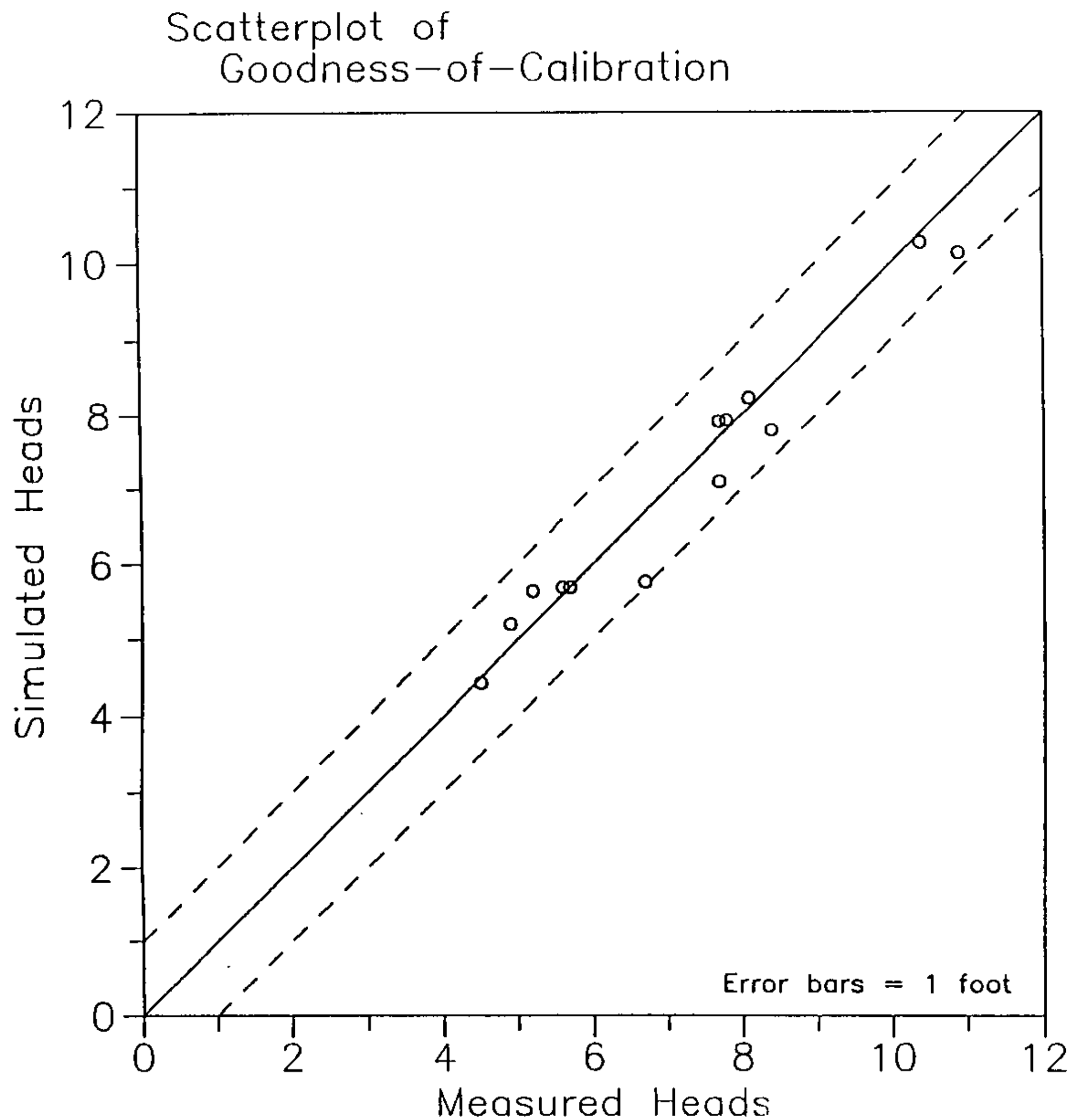
[7]A MODFLOW utility program by Geraghty & Miller, Inc.

Reduction in Mean Absolute Error During Calibration



Simulations prior to No. 4 used one stress period with annual average recharge, No. 4 – 13 used four stress periods with quarterly average re–charge, for simulation times of one year. No. 14 – 23 used twenty stress periods with quarterly average re–charge, for simulation times of five years.

FIGURE 20



Data includes 11 wells in layer 2 and 2 wells in layer 3.

FIGURE

The verification used a trial-and-error methodology similar to the calibration procedures. The model was run, results were plotted as a hydrograph, model-generated and field-generated hydrographs were compared, adjustments made to the storage parameters, and the model re-executed.

The first verification run produced a hydrograph whose water level trends nearly matched the field-generated hydrographs, but whose amplitude was too large. Adjustments to the storage coefficient were made which gradually lowered the hydrograph amplitude so that the hydrographs matched better. For the final verification run, when the stress periods were changed to reflect months rather than quarters, the trends and amplitudes of the model-generated hydrograph closely matched the field-generated data (Figures 22 - 23). However, the model-generated data appears, in general, to be several feet higher than the field data. This may be a function of using the wrong starting head for the verification runs. The starting head for the first two verification runs was the head generated by the calibration. For the last two verification runs, the calibration head was modified to reflect pumping prior to the verification period. However, this lowered the head by less than a foot and had little effect on the runs.

Further verification runs were not made because of the uncertainty in the starting head values. The model adequately simulates water level trends and amplitude of water level changes. Hence with the correct starting head values, the model should be able to predict water levels for given production and precipitation data sets.

2.11.6 Model Prediction

Following verification, a sensitivity study on the effects of hydraulic conductivity and vertical leakance was performed (Appendix 9), then the model was used to estimate the maximum production limits from the two Westport well fields during drought conditions. The model was run for a period of one year, from October through September. The starting heads were taken from the low point of the verification run, with the water level elevation at the North Field at 3 feet above sea level and the elevation at the South Field 7 feet above sea level. These heads are slightly higher than the water levels measured at the well fields in October, 1993 (see Appendix 2). The recharge applied to the model represented recharge estimates made from 1985 precipitation data (Table 12), comprising approximately 60% of the normal annual recharge. This data set approximates, based on the 40 years of record, the 8th driest water year in a 100-year period.

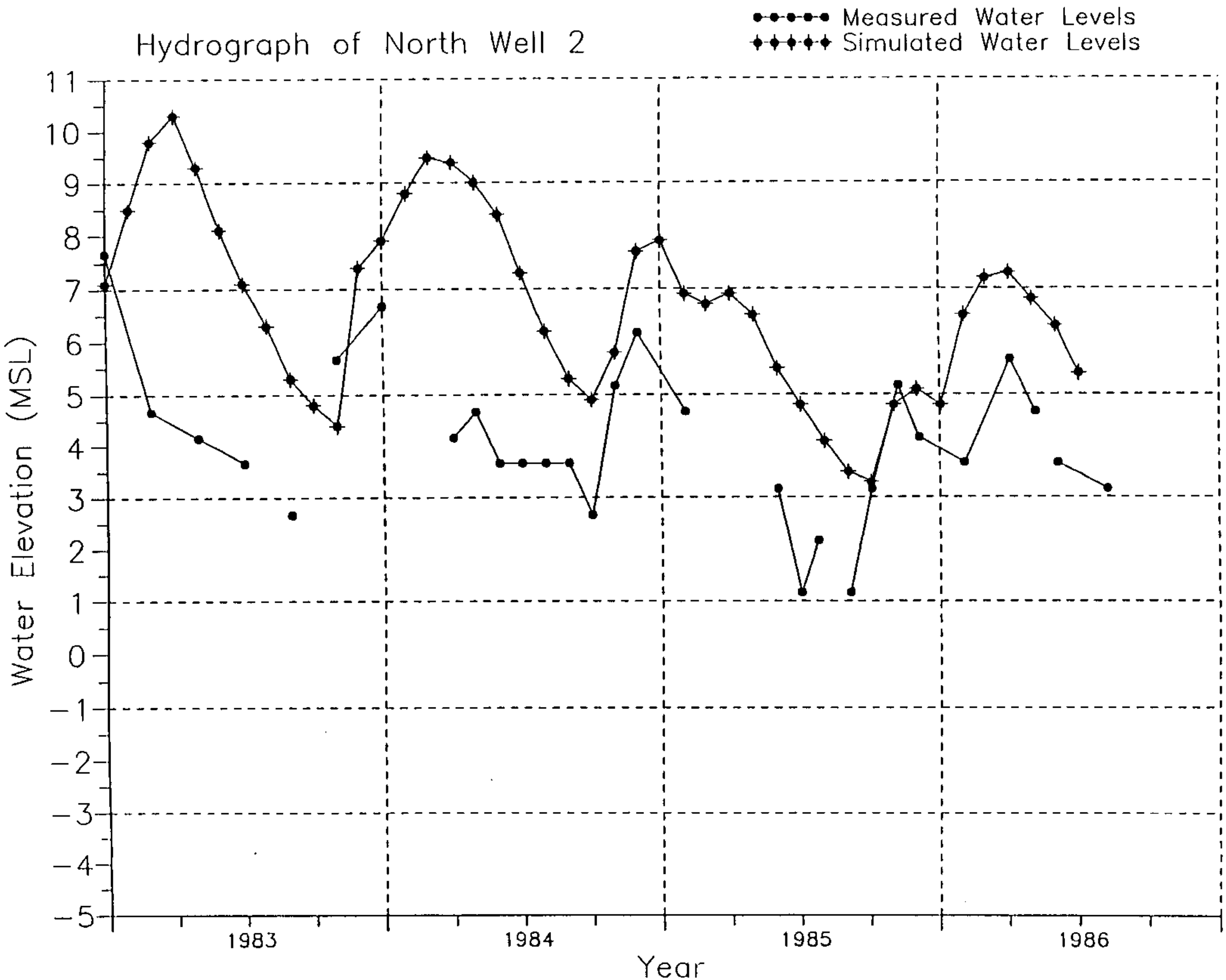
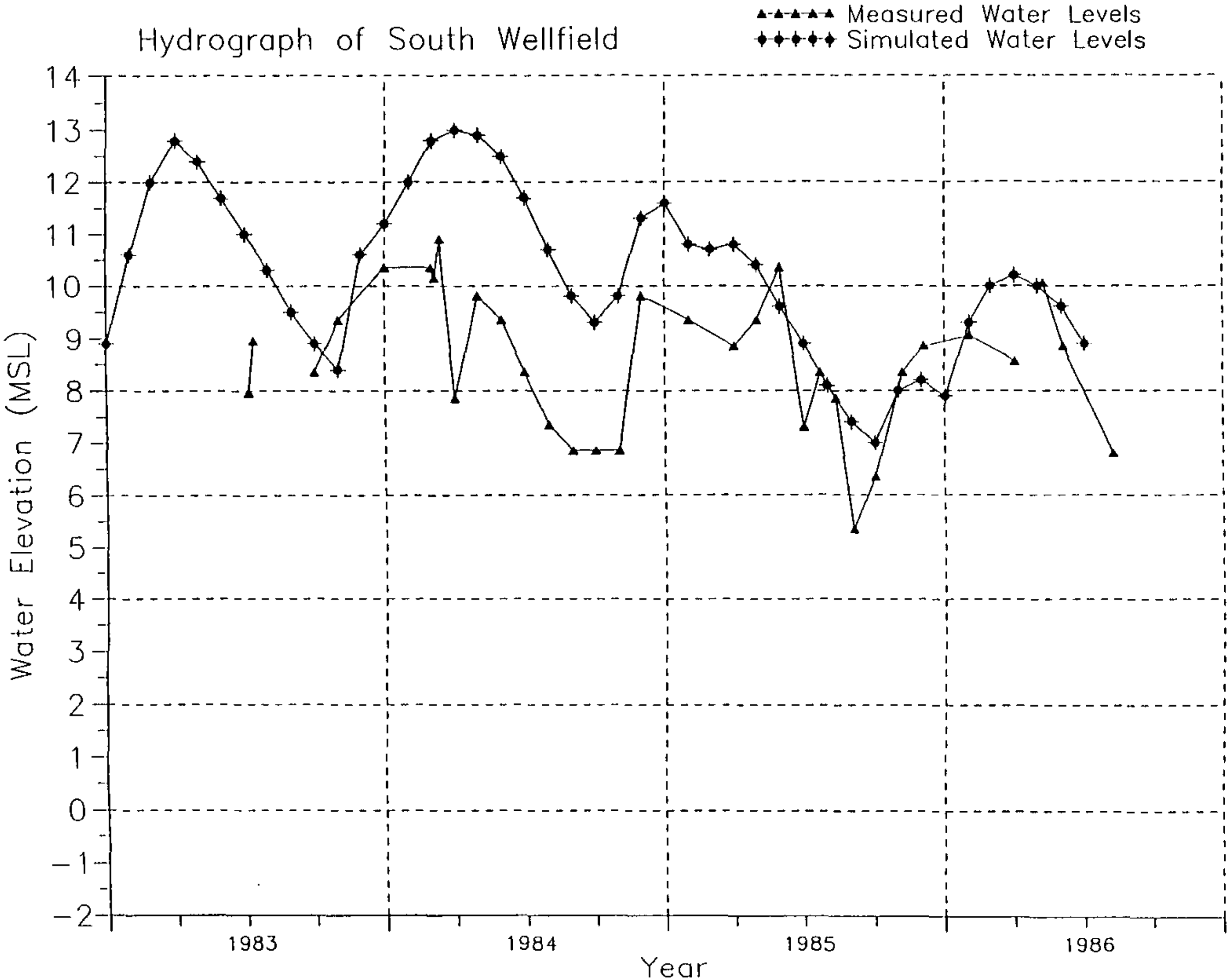

Hydrograph of North Well 2
Measured Water Levels
Simulated Water Levels
Water Elevation (MSL)
11
10
9
8
7
6
5
4
3
2
1
0
−1
−2
−3
−4
−5
1983
1984
1985
1986
Year

FIGURE 2



Highest water level recorded at the four south wellfield wells.

FIGURE 23

Table 12

RECHARGE VALUES USED IN PREDICTIVE SIMULATIONS, IN INCHES

	1985 Precipitation[1]	Estimated Recharge[2] Used	Estimated Normal Recharge[2]	Deviation From Normal
Oct	12.12	10.4	4.9	+5.5
Nov	6.18	4.9	8.7	-3.8
Dec	2.99	1.8	11.0	-9.2
Jan	0.88	0.0	10.3	-10.3
Feb	5.25	4.1	7.4	-3.3
Mar	7.75	6.0	6.3	-0.3
Apr	4.92	2.7	2.6	+0.1
May	1.15	0	0.2	-0.2
Jun	2.89	0	0	0
Jul	0.36	0	0	0
Aug	1.08	0	0	0
Sep	3.67	1.5	1.3	+0.2
Total	49.24	31.4	52.7	-21.3

[1]Measured at Grayland
[2]Assumes no runoff, assumes Tracy (1978) estimated evapotranspiration

To find the maximum production limits with these conditions, a trial-and-error approach was used. The model was run with varying amounts of production until the lowest simulated heads at the well fields during a specific run were at sea level. The first run used the actual monthly production values from 1989. That production rate resulted in below sea level heads at the North Field and above sea level heads at the South Field (Table 13).

Table 13

PREDICTIVE SIMULATION RESULTS

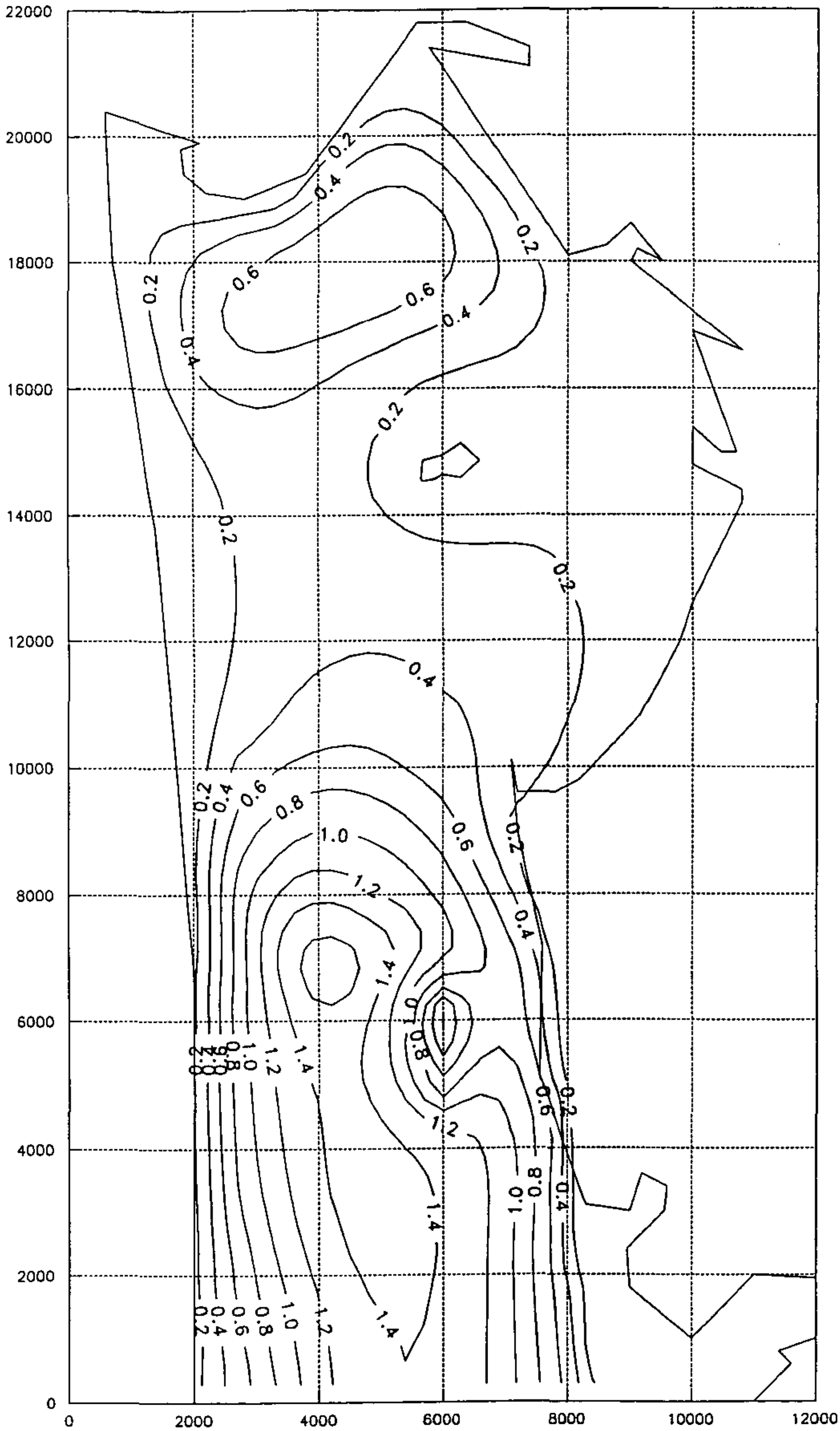
Run #	North Field		South Field	
	Production (mg)	Resultant Head (ft, MSL)	Production (mg)	Resultant Head (ft, MSL)
1	204	-0.9	35	1.5
2	180	-0.7	60	1.0
3	130	-0.3	110	-0.4
4	110	-0.2	90	0.1
5	100	-0.1	90	0.1
6*	100	-0.2	90	-0.2

*Runs 1-5 used constant production, run 6 used production values that reflected monthly demand.

The fifth predictive simulation resulted in heads close to sea level (Figure 24). For this run, the North Field wells were pumped at a constant rate of 190 gpm (2 wells at 95 gpm each) producing 100 million gallons in the one year period. The South Wells were pumped at a constant rate of 171 gpm (4 wells at 42.75 gpm each), producing 90 million gallons.

To investigate the effect of seasonal pumping on the water levels, the total production values for the two well fields from run 5 were multiplied by the monthly average production percentages (from 1986-1991 data) to produce monthly production values (Table 14). The model was then run with these monthly changes in production. However, the results were not significantly different then the previous run.

Model-Generated Heads at Estimated Safe Production Level



North Field producing 100 MG annually, South Field producing 90 MG annually. Severe drought conditions.

Contour Interval 0.2 feet.

Table 14

MONTHLY PRODUCTION VALUES FOR RUN 6

	Percent of Total Annual Production	North Field Production (mg)	South Field Production (mg)	Total Production (mg)
Jan	7.1	7.1	6.4	13.5
Feb	6.9	6.9	6.2	13.1
Mar	7.2	7.2	6.5	13.7
Apr	8.1	8.1	7.3	15.4
May	9.2	9.2	8.3	17.5
Jun	9.3	9.3	8.4	17.7
Jul	10.8	10.8	9.7	20.5
Aug	11.1	11.1	10.0	21.1
Sep	9.1	9.1	8.2	17.3
Oct	8.3	8.3	7.5	15.8
Nov	5.9	5.9	5.3	11.2
Dec	7.1	7.1	6.3	13.4
Totals	100.1	100.1	90.1	190.2

Models Assumptions and Limitations - Numerous assumptions and approximations were used in the construction of the Westport model. The model results must be used with a recognition of the uncertainty in the model construction and the uncertainty in the modeling process itself. The major assumptions used are listed below:

- Layer 1 and 2 bottom elevations are estimated at most locations; layer 3 bottom elevation is estimated everywhere.
- Hydraulic conductivities away from the north and south well field areas are largely assumed.
- Vertical permeability (leakance) is assumed everywhere.
- Storage coefficients are assumed everywhere.
- The possible effects of lakes and swamps in the model area were ignored.

- Recharge was estimated by subtracting estimated evapotranspiration (Tracy, 1978) from measured precipitation values at Grayland. Runoff was assumed to be negligible.

- Recharge infiltration rates were assumed to be constant everywhere.

- Ground water flow into and out of the Satsop Formation was assumed to be negligible.

- Tidal effects were assumed to be negligible.

- Buried sediments in Grays Harbor and south Bay were assumed to be in direct hydraulic continuity with the salt water.

- Wells are assumed to be fully penetrating and 100% efficient.

- Well production was assumed to be constant during stress periods (one month, three months, or a year depending on the run).

The model error can be seen in the final verification run. While the simulated hydrographs resemble the field-generated hydrographs, they are not an exact match. In particular, the model-generated hydrographs are several feet higher than corresponding field-generated data. Additionally, the trends expressed by the two hydrographs are not always consistent. The field-generated data of North Well 2 in early 1983 shows a declining water level, the model predicted a rising, then falling water level.

Model error is a consequence of the model not accurately reflecting the natural hydrologic system. In this case, the model was constructed to generally reflect the natural system, but lack of data prevents a closer match to the natural system. For a better definition of the natural system, extensive well testing and water level monitoring, possibly coupled with additional test drilling, would be necessary.

Another source of model error is the lack of previously collected water level data and occasional missing water production records. Both the calibration and verification are somewhat suspect because of the sketchy water level data. The monthly collection of accurate water level and production data is highly recommended so that a post-audit of the model can be conducted in the future to check the accuracy of model results.

Even with the uncertainties involved, the model represents our best understanding of the system based upon our current level of knowledge. The model has provided valuable insights into how the hydrologic system operates and reacts. We believe the model has provided a good estimate of production available from the current Westport well fields. However, the model predicted water levels may be higher than actual water levels under the same conditions. Consequently, the model cannot replace adequate record keeping and water quality monitoring.

2.12 WATER AVAILABILITY

Between 1986 and 1991, the average annual Westport ground water production was 217 million gallons. The numerical model suggests this production rate could lead to potential salt water intrusion. Using the drought recharge values on Table 12 and dividing the 217 mg production between the two well fields (115 mg from the North Field, 102 mg from the South Field), the model predicted resultant heads to fall slightly below sea level at both the North and South Field (Figure 25). If the average field production volumes are used (152 mg at the North Field and 65 mg at the South Field) instead of a nearly even division of the total production, a significant area around the North Field has a head below sea level (Figure 26). Salt water intrusion is possible whenever the head at the well fields falls below sea level, the lower the head, the more likely intrusion becomes.

To best protect against salt water intrusion, the head at the well fields should not be allowed to fall below sea level. Using this as a criteria, the model predicted safe annual production rates of 100 mg and 90 mg for the North and South Fields respectively during drought years.

This safe annual production rate represents our best conservative estimate of a production rate which will not cause salt water intrusion. During non-drought years, more water can safely be produced. Consequently, recent and current production levels have not resulted in detectable salt water intrusion. But, if an extreme drought does occur, the City may induce a problem with the current production levels.

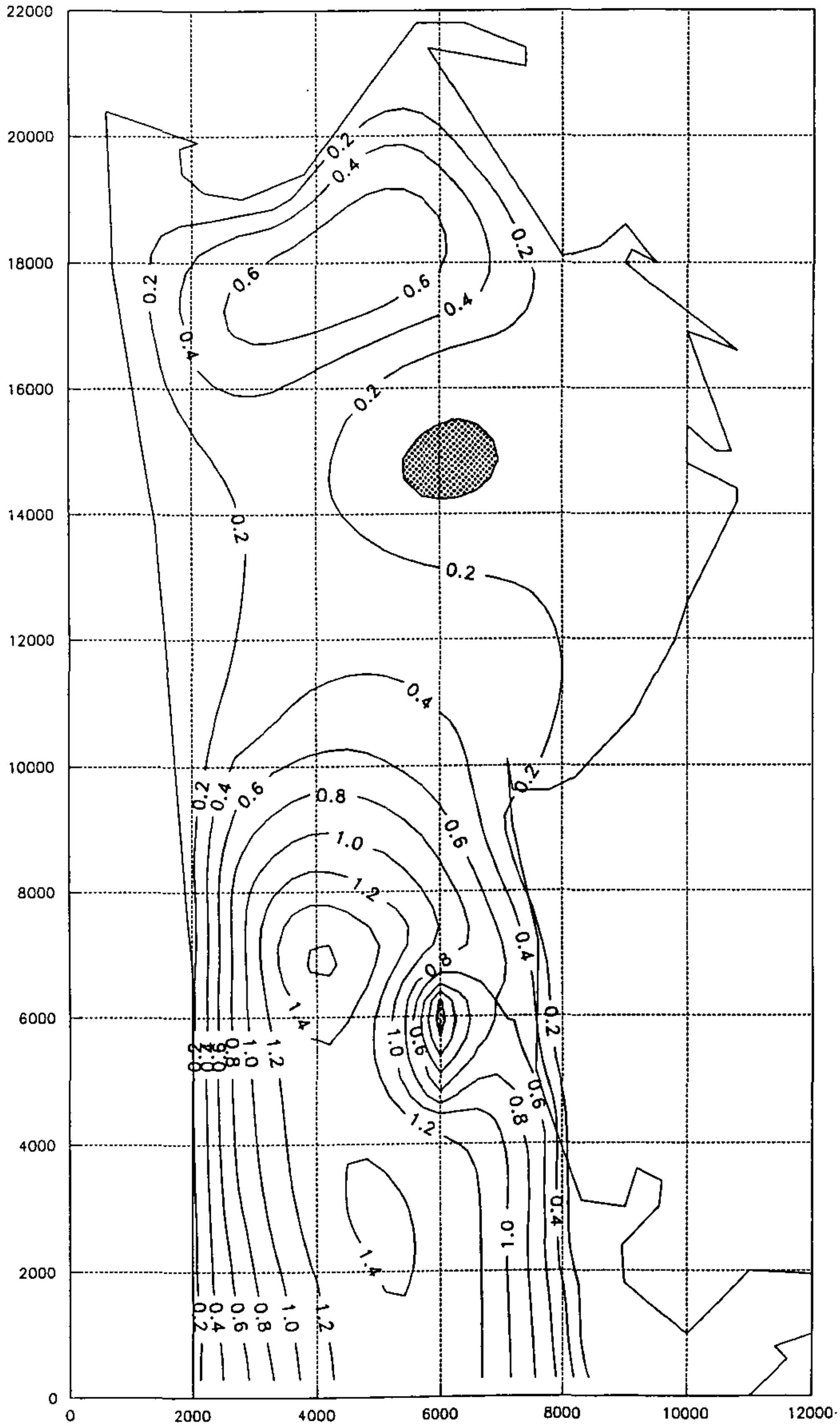
To prevent this problem, the City needs to develop one or more additional sources of water. There are two major options available to develop additional ground water supplies: 1) develop one or more new well fields on the peninsula, or 2) develop water south of the City by drilling production wells into the Satsop Formation.

Additional water is available on the peninsula, but not from the present well fields. In an average year approximately 12,600 acre-feet of precipitation recharge occurs on the peninsula. Even in a severe drought year, a very large amount of precipitation recharge occurs (Table 15). Yet the recommended safe production rate of 190 mg per year is equivalent to 583 acre-feet, less than 10% of the recharge over the entire region or approximately 15 to 25% of the recharge within the combined capture zone[8] areas for the two well fields.

---

[8]Capture zones were estimated by examining the numerical model generated head map.

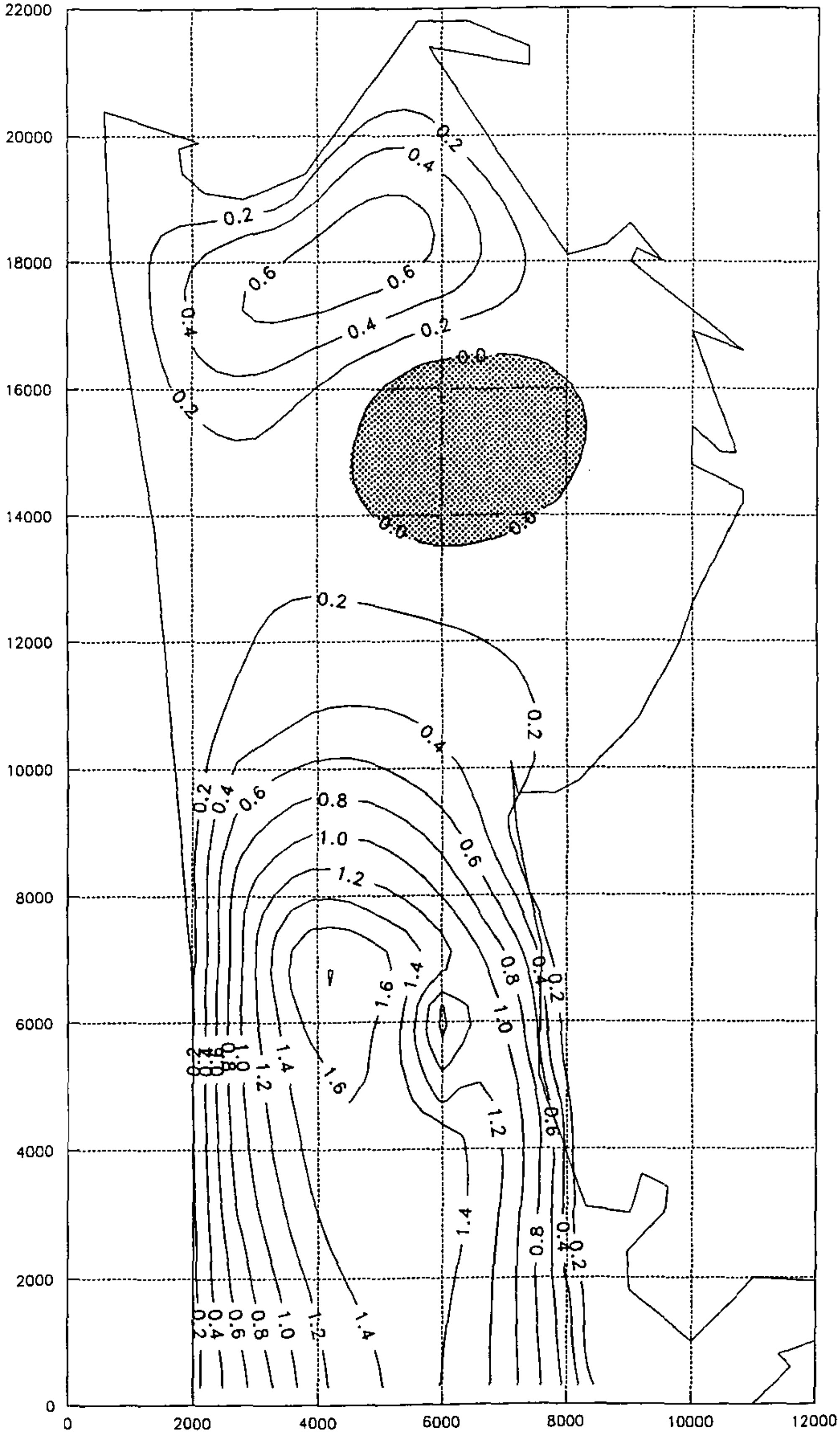
Model-Generated Heads, Average Production, Drought Conditions



North Field producing 115 MG annually, South Field producing 102 MG annually. Stippled area heads are below sea level.

Contour Interval 0.2 feet.

Model-Generated Heads, Average Production, Drought Conditions



North Field producing 152 MG annually, South Field producing 65 MG annually. Stippled area heads are below sea level.

Contour Interval 0.2 feet.

Table 15

PRODUCTION LIMITS AS PERCENTAGE OF RECHARGE

	Recharge (af)		190 mg Production as percentage of recharge	
	Total Peninsula	Capture Zones	Total Peninsula	Capture Zones
Average Year	12600	3975	5	15
Drought Year*	7500	2355	8	25

* Based on 1985 precipitation data at Grayland, equivalent to the 8th worst water year out of 100 years.

The 15 to 25 percent recoverable recharge is similar to figures generated in other studies. Tracy (1978) estimated 12 inches per year out of a total of 54 inches of recharge, 22%, could be developed. John Noble, in a 1986 study for the City, estimated a North Field production range of 12 to 24% of the estimated annual North Field recharge of 5080 acre-feet.[9]

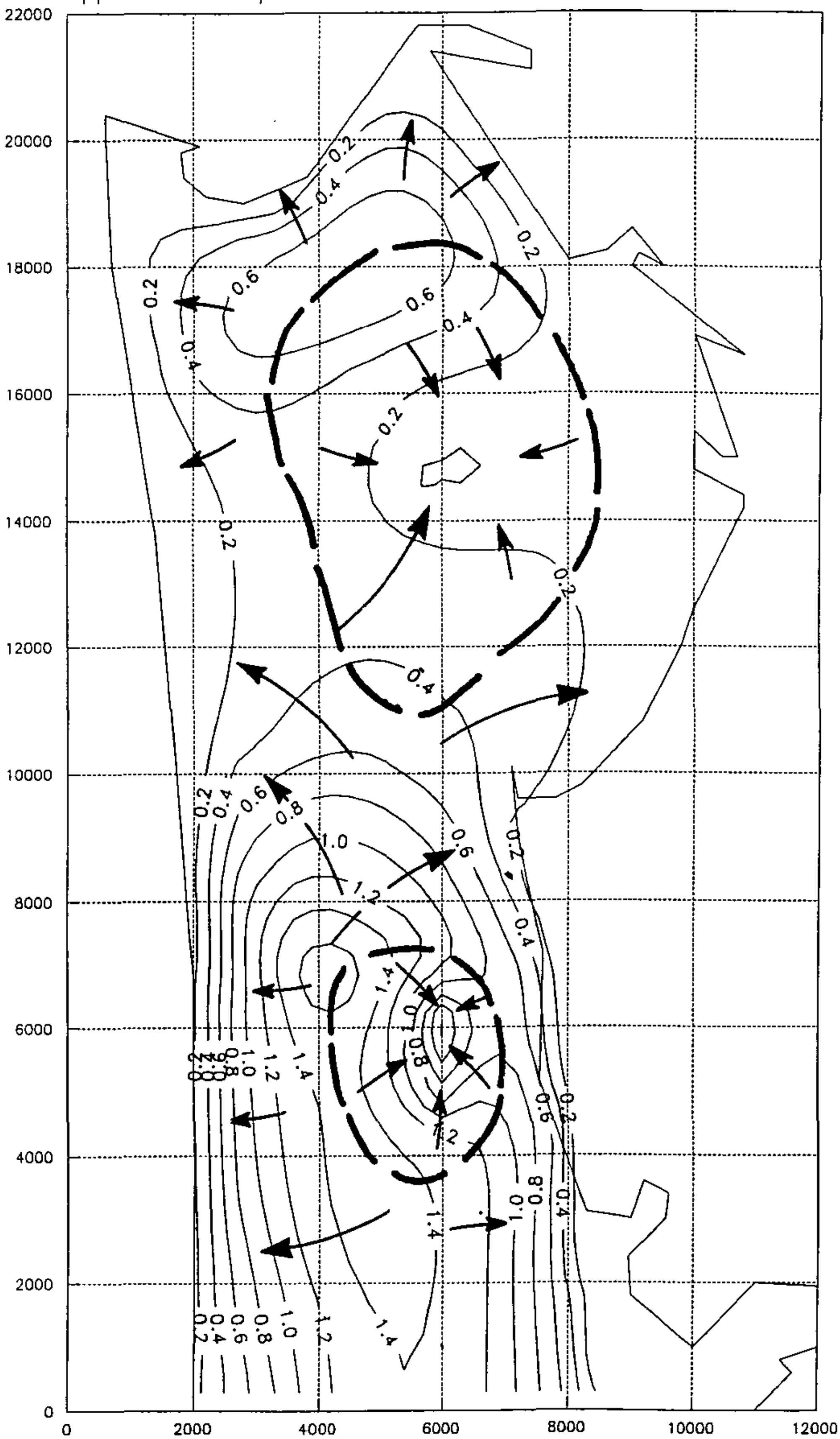
To increase production, the area contributing water to wells must be increased without allowing for salt water intrusion. The model generated head map for drought conditions shows the flow direction for most the ground water on the peninsula is toward the ocean and Grays Harbor, not toward the wells (Figure 27). To increase production, a new well field is needed to intercept flow that is now draining toward the salt water. Perhaps the best location for the new field is midway between the present well fields, near the intersection of Hancock Avenue and Forrest Street (NW quarter of NE quarter of Section 13). Such a field could potentially produce 50 to 100 mg annually.

The second option to develop additional water is to drill in the Satsop Formation. Yields and water quality of wells in the Satsop Formation vary widely. Consequently, it would be best to drill at a known location with good water quantity and quality. As such, the Roberts Farm represent the best choice of possible sites. The Roberts Farm test well (Ref. No. 14) was drilled in 1974. The well encountered an aquifer in the Satsop Formation located between 137 and 300 feet below ground. The water in the upper part of the aquifer had a high iron content, but the quality in the lower part of the aquifer was good.

A pump test revealed the aquifer to have a transmissivity of nearly 29,000 gpd/ft. The test well was pumped at 195 gpm with a specific capacity of 3.2 gpm per foot of drawdown. A large

[9]Noble used a larger capture zone than used here.

Approximate Capture Zones and Ground Water Flow Directions



North Field producing 100 MG annually, South Field producing 90 MG annually. Severe drought conditions.

Contour Interval 0.2 feet.

diameter production well at this location could potentially produce 1000 gpm. However, before the site is used for production, testing would be required to address potential water quality problems, specifically, the chance of causing salt water intrusion and the potential for drawing the bad quality, upper aquifer water into the well.

Because of these potential problems, a single, high-capacity well may not be the optimum way to develop the site. Such a well will likely impose up to 100 feet of drawdown. This drawdown would probably cause the lower quality water at the top of the aquifer to migrate downward. The well may also cause the aquifer head to fall below sea level under a portion of the South Bay tidal flats, allowing for possible salt water infiltration into the materials above the aquifer. While the aquifer is protected by an extensive clay layer (approximately 100 feet thick at the site), maintaining aquifer heads below sea level could potentially lead to salt water leakage into the aquifer. Also, maintaining aquifer heads at a level low enough to cause salt water infiltration would certainly cause the downward migration of the upper, low-quality water.

To prevent these potential problems, the site should be developed with several wells to keep the cone of depression from becoming too deep at any one well. Additionally, several monitoring wells completed in shallow sand layers above the main aquifer should be constructed to monitor for potential salt water intrusion.

2.13 HYDROGEOLOGIC CONCLUSIONS

There are three major geologic deposits in the Westport area: alluvial sediments, the Beach Deposits, and the Satsop Formation. The Satsop Formation is the oldest of the units. It is a semiconsolidated sequence of clay, silt, sand and gravel. Discontinuous, coarser zones are waterbearing and supply production for many wells on the South Beach. Water quality in the Satsop is variable depending on depth and location. The top of the Satsop Formation deepens to the north. A productive zone in the Satsop at Roberts Farm provides a potential new water source for the City. Along the east side of the peninsula, alluvial sediments overlie the Beach Deposits. These sediments are fine grained and are generally not used for ground water production.

The Beach Deposits overlie the Satsop Formation. These include sand, occasionally gravelly, deposited by the longshore current or as dunes. These deposits thicken and become coarser to the north. All known wells on the peninsula north of the high school appear to be completed in the Beach Deposits, including the City's wells at the North and South Fields. Recharge to the Beach Deposits is from local precipitation. Water quality in the Beach Deposits is generally good. Along the east side of the peninsula, alluvial sediments overlie the beach Deposits. These sediments are fine grained and are generally not used for ground water production.

Between 1986 and 1991, the South Field has averaged 65 million gallons in annual production; the North Field has averaged 152 mg. Water levels at the fields appear to have fallen slightly over time, but the trend is uncertain due to inadequate water level record keeping. The water levels appear to be closely tied to precipitation recharge, rising in the winter and falling in the summer.

Ground water recharge on the peninsula is entirely from precipitation. Based on precipitation records for Grayland, the estimated annual recharge at Westport is 53 inches, 92% of which occurs between October and March (inclusive). On average, 42% of the well production occurs during the same time period. Over the forty years of record, estimated water year (October through September) recharge has ranged from 26 to 80 inches. During the past 17 water years, 12 have had below average recharge, including 1992 and 1993.

To assist the City with monitoring of water levels and water quality, five monitoring wells were drilled, three on the peninsula into the Beach Deposits, two on South Beach into the Satsop. The wells provided needed information in the creation of the numerical ground water flow model. The new monitoring wells together with previously drilled monitoring wells provide the City with an excellent monitoring network, albeit with a "hole" at the South Field, to guard against salt water intrusion. To complete the monitoring system, a well east of the South Field needs to be added to the network.

A ground water flow model of the Westport peninsula was constructed using numerical finite-difference techniques. The model was calibrated to measured water levels at the North and South Fields from 1983 through 1986. The model was used to predict aquifer head in the Beach Deposits during a severe drought. Thirty-one inches of recharge was used in the model simulation, this amount is equivalent to the 8th driest year in a 100-year period. With this scenario, the model predicted that annual well field productions greater than 100 mg at the North Field and 90 mg at the South Field would cause aquifer heads to fall below sea level, a condition required before salt water intrusion can result.

Although the city currently produces more than the annual safe predicted limit of 190 mg, salt water intrusion has not been detected to date. There may be several reasons why this is so. First, the model results are an estimate because the model does not exactly duplicate the natural system and, therefore, contains a certain amount of modeling error. Second, the predicted safe limit is conservative because it is based upon water levels reaching sea level at the well fields rather than the water levels reaching sea level at the shoreline. Third, while the last several years have had lower than normal recharge, they have not had recharge deficits as large as used in the model predictions. And finally, monitoring efforts by the City have been inconsistent in the past. The QC wells were constructed in 1976 to test for water quality changes, yet adequate water chemistry data from these wells was not available. Consequently, salt water encroachment may actually have occurred in the past but wasn't detected because of a failure to monitor, or because it occurred away from a monitoring well.

To best protect against salt water intrusion, the City should consistently use the monitoring network and find a new source of water to relieve pressure on the present well fields. Additional water is available on the peninsula. A new well field located approximately halfway between the two existing fields could potentially produce 50 to 100 mg annually without detrimental effects.

Further south the City could develop a new source from the Satsop Formation at Roberts Farm. At that location, up to a 1000 gpm instantaneous capacity may be available. However, because of poor water quality in the upper portion of the aquifer and the site's proximity to South Bay, several wells should be used to maximize production at the site rather than a single, high-capacity well.

III. SURFACE ACTIVITIES

3.1 Plans and Studies

Over the years several plans have been developed, studies conducted, and reports written relative to the use and potential impacts of surface activities on Westport's groundwater resource. In 1968 a comprehensive plan (land use) was developed for the City, followed by a new plan[1] in 1986. A Water System Plan[2] was first developed in 1979 and revised in 1984. A new comprehensive water plan is now under development. The City has never had a complete general sewer plan, other than engineering reports, etc., for its sewerage facilities. A Comprehensive Sewer Plan is currently being prepared. At this writing, Grays Harbor County has completed Phase I of a two phased Utilities Comprehensive Plan[3]. Phase II is to follow. In March, 1992 The Grays Harbor Regional Planning Commission published a preliminary classification report of natural resources lands and critical areas[4] for the City of Westport. The formal report was adopted by the City Council under Resolution No. 497 on May 12, 1992.

Two reports have been prepared that deal specifically with groundwater issues and discuss recharge from the surface. The first was a January, 1971 report on an observation of a test well for possible salt water intrusion[5]. The location of the observation well is near the southeast corner of Twin Harbors State Park. The second was an evaluation of groundwater supplies in 1986 for a potential fish farming operation[6]. This report evaluated the ability of the City of Westport to provide additional water for fish farming operations.

Presently, Grays Harbor County does not have a Coordinated Water System Plan in place. However, County staff is working with DOH officials to possibly develop and implement such a plan.

3.2 Land Use

3.2.1 City of Westport

On August 25, 1986 the Westport City Council passed Ordinance No. 791, which officially adopted a new comprehensive plan[1]. The plan addresses land use goals, objectives, and policies of the City of Westport. The City designated certain areas for specific land uses, with the border areas viewed as transitional (See Figure 3.1). However, Chapter 4, LAND USE ELEMENT, specifically addressed the issue of groundwater and surface activities in Section F. The following is taken from The City of Westport's comprehensive Plan:

> F. GROUNDWATER, STORM WATER RUNOFF/DRAINAGE
>
> The land use development process impacts a variety of items; however, particular concern is necessitated to issues relating to groundwater and storm water/drainage. This emphasis on these

issues within this comprehensive plan is recognized in state law (RCW 35A.63.061) which states in part, 'The land use element shall also provide for protection of the quality and quantity of groundwater used for public water supplies and shall review drainage, flooding and storm water runoff in the area . . .' To address this requirement, the following establishes direction and provisions for the city in relation to groundwater and storm water runoff/drainage.

Groundwater

According to the Westport 1984 Water System Plan, Westport utilizes the groundwater of the Westport Peninsula as its source of supply. Salient points identified in the plan regarding the groundwater source include: a) the Westport aquifer is potentially sensitive to saltwater intrusion resulting from over pumping, b) no deterioration of the resource has occurred to date, c) no estimates have been made regarding the volume of the groundwater resource. Thus, the city may have a system approaching aquifer capacity or, conversely, there may be substantially more water available without resource deterioration; and d) the catchment basin (of precipitation recoverable by the wells) has not been defined.

With this and other information for the 1984 Water System Plan serving as background, the following goals, objectives, and policies have been developed relating to groundwater protection.

GOALS:

To protect the quantity and quality of groundwater in the Westport area.

OBJECTIVES:

1. To maintain high quality water by assuring that adjacent land uses are compatible with water source areas.

2. To maintain an adequate volume of the groundwater resource for users by monitoring the impact new uses will have on water quantity.

POLICIES:

1. Implement the 1984 Water System Plan, especially those items relating to groundwater quality and quantity.

2. The city should protect aquifer recharge areas from development which may reduce or contaminate groundwater resources.

3. The city should review and limit incompatible development in watersheds servicing public water supplies, and review development proposals for potential adverse impacts to those water supplies.

4. Evaluate the potential impacts of major development, particularly industrial or processing, upon quality and quantity of groundwater in the Westport area. Particular attention should be given to the impact of those uses requiring quantities of water seriously affecting the capacity of the Westport water system.

5. The city shall use the State Environmental Policy Act (SEPA) review process as one means, but not necessarily the only, of determining the impacts which major actions might have on the city's groundwater resource.

6. The city should continue to cooperatively plan with the Grayland water system concerning the area south of the city limits. Such planning may, for example, involve connecting with the Grayland water system.

By inclusion of the above statement in the city's comprehensive land use plan, Westport recognized the importance of groundwater as its source of potable water. Actions taken to protect that source include designating commercial and industrial use areas away from the immediate area of the city's wells in the North Field. The South Field is located outside the city limits, but the comprehensive plan addresses this situation by adopting the following policy in Chapter 8, AREAWIDE DEVELOPMENT ELEMENT:

2. The city shall promote the protection of the character, the environmental amenities, and the natural resources, especially the groundwater resources of the Westport area.

The Washington State Growth Management Act (GMA) of 1990 required the City of Westport to designate its natural resource lands and critical areas[4]. One element, as in the Comprehensive Plan, is dedicated to the designation of aquifer recharge areas. The city evaluated the minimum classification guidelines, general description of the area, and local conditions, and subsequently designated the entire area of the city as an "Aquifer Recharge Area." The city's policy statement is as follows:

> The City of Westport has considered the GMA definitions for aquifer recharge areas, the DCD (Washington State Department of Community Development) Minimum Guidelines, and the discussion and mapping for the water and wastewater planning element of the 1991 *'Grays Harbor County Utilities Plan, Phase I'*; and having determined that the entire City is underlain by an undefined aquifer; designates the entire area of the City as an Aquifer Recharge Area.
>
> The City of Westport recognizes its Aquifer Recharge Area designation as a preliminary designation. The City of Westport is committed to protecting water quality within the City and to compiling additional information through research, monitoring, and groundwater studies that will be needed to further classify and designate aquifer recharge areas used for potable water and that are vulnerable to contamination that would affect the potability of the water. It is also the intent of the City of Westport to coordinate with Grays Harbor County and other public and private entities to identify and protect drinking water supplies.

3.2.2 Grays Harbor County

Grays Harbor County has a Comprehensive Plan for the unincorporated areas of the county. There is no one single document that serves as the foundation of the plan. The plan as a whole is comprised of several elements that were adopted by the Grays Harbor Board of County Commissioners. Elements of the plan impacting land use in the South Beach area include the Shorelines Master Program, Ordinance No. 38, the County's Zoning Code, The Estuary Management Plan, Rural Lands Element, and Agricultural Element. On April 6, 1992 the County adopted "Interim Resource Lands and Critical Areas Designations" as an amendment to the plan. The following statement is contained in the Introduction of the Designation Amendment:

Grays Harbor County is not required to plan under the GMA. Nevertheless, the county does recognize the importance of comprehensive planning and is participating in a county wide long range planning effort that incorporates those aspects of the GMA that are relevant to local needs and circumstances, and achievable within the staffing and financial constraints currently facing the county. the goal of this planning effort is to cooperatively develop "county-wide planning policies" with other local jurisdictions within the framework specified in RCW 36.70A.210 County-wide Planning Policies. However, because the county has decided not to "opt-in", its planning process is not bound by the time-table dictated in the GMA.

Overall, the concerns which prompted development of the GMA such as urban growth, sprawl, congestion, and the loss of open space are not generally applicable to Grays Harbor County. As a result, the Amendment to the Grays Harbor County Comprehensive Plan uses the existing regulatory network as a basis for classification and designation of resource lands and critical areas. The designation of districts either coincides with existing jurisdictional boundaries (i.e., agricultural lands, floodplains, and shorelines), or uses criteria from the Uniform Building Code (i.e., geologically hazardous areas). certain designations such as volcanic hazard areas and fish and wildlife habitat are considered inappropriate by the county and are reserved for future consideration. No changes to existing regulation or creation of new regulations are recommended.

For the purposes of this characterization study, the important element of the County's Resource Land and Critical Areas Designation is the Aquifer Recharge Area designation. The county recognized its responsibility towards understanding of its groundwater and the potential threats to the resource. A Comprehensive Utility Plan[4] was adopted in 1991. The plan contains an inventory of existing water facilities and groundwater supplies and existing wastewater facilities and an evaluation of soil types able to support wastewater disposal systems.

Most of the area is zoned Residential or General for the purpose of future development. Some parcels along SR-105 are designated as Commercial. There are no Industrial land uses designated in the unincorporated South Beach Area. See Figure 2.2 in the pocket at the back of this report for the county's designated land use codes.

Not enough information was available on aquifer location, size, yield, or their susceptibility to the effects of high density development of on-site septic systems. Therefore, it does not, address susceptibility of aquifer recharge areas to contamination from land use activities such as on-site septic systems with the potential groundwater pollution. To that end, the county entered into an agreement with the City of Westport to study and characterize the groundwater underlying the city and South Beach area[8]. This study will provide the county with a tool with which it can plan for the orderly development of the South Beach area.

3.3 Population

The City of Westport and South Beach area have a small, but fairly consistent permanent, year-around population base. However, during the summer the population will swell to many times that level. The study area is a destination location for many vacationers and tourists. Three different population groups have previously been identified for Westport[2]. They are permanent residents who reside in the area throughout the year, seasonal residents who spend two or more weeks there, and transients who reside in the area for less than two weeks. Table 16 lists the permanent population for the South Beach area from 1960 to 2010.

Table 16

SOUTH BEACH PERMANENT POPULATION*

Year	Westport	Grayland
(Actual)		
1960	976	---
1970	1,364	unknown
1980	1,954	unknown
1990	1,892	920
(Projected)		
2000	2,200	unknown
2010	2,400	unknown

* Grays Harbor Regional Planning Commission (GHCRPC) Census Data

As can be seen, the study area enjoyed a consistent population growth until 1980. Since then, the total population has actually shown a slight decline. The 1991 and 1992 population, as reported by GHCRPC, is 1,890 and 1,920, respectively, which indicates a return to a growth period, albeit at a somewhat lower rate than the 1960 to 1980 period. New building permits issued by Westport for 1992 indicate a slightly higher short term growth rate, with 16 permits for residential construction having been issued. Additionally, two permits were issued for new commercial buildings, one of which was for combination residential/commercial construction.

The permanent population depends on many variables, including birth rate, death rate, and migration patterns. The permanent population is primarily dependent on employment opportunities, which in the case of Westport has shown substantial fluctuations. Employment in the area is highly dependent on fishing, crabbing, clam digging, and sightseeing all of which bring in the seasonal and transient population. All except general sightseeing rely on year-to-year regulations which are governed by availability of the specific resource.

Regarding future employment opportunities, the City of Westport, the Port of Grays Harbor, and Grays Harbor County have received several inquiries for new industrial and recreational development. At this writing, only one of the inquiries is at a point of becoming a fact. The possible fish farming operation to be located in an area zoned as Marine Industrial at the southeast end of the Westhaven District, was seriously pursued by the developer. A financing problem arose which has impeded further development of this venture. While City personnel do not believe this particular endeavor will go forward, only recently the Port of Grays Harbor has received another request from a different fish farming venture for information regarding possible location in Westport. Details on this latest request are not available at this writing.

Recently, interest has been shown in placing a large condominium and a destination resort with a hotel, convention center, and an 18-hole golf course, in Westport. The condominium, to be located in the western area of the city along Ocean Avenue, between Surf Street and the ocean beach, would initially have approximately 365 units, with a maximum of 450 units, and be for both permanent and transient population use. The destination resort would occupy an area zoned for Tourist Service between Westhaven State Park and the Westport Light State Park west of North Montesano Street. The condominium/motel project is in the permit review process to begin construction in 1994. The destination resort project is presently undergoing the environmental review process. These projects will provide several new employment opportunities.

Another project that came to light as this study was being conducted is a new amusement park on 24 acres in the vicinity of Clark Street and Montesano, in the Westhaven area. As this report is being written, construction has already begun on the first phase, a go-cart track. Future phases include a water theme park with a water slide and wave pool. While this project will provide for additional employment opportunities, it may also have a serious effect on the future use of the aquifer. At this writing, the park has not submitted to the city an estimation of its water needs for the water slide and wave pool.

The annual increase in seasonal and transient population begins in the spring when whale watching begins as the California Gray Whales migrate north to their feeding grounds in the waters off Alaska. Later on, the population increases again with the advent of the various seasons for fishing, crabbing, and clam digging. The length of the season determines the length of time and stability of the increase. The true tourist season begins around Memorial Day and lasts until Labor Day, when it begins to ease. The tourist season also coincides with the period of least recharge potential for the groundwater. Additionally, continued good weather, as in 1992, will tend to keep the total number of daily tourists up, thus a longer and potentially stronger impact on the aquifer will occur. The peak days are weekends and the Fourth of July. Peak day population can reach a level more than 30 times the permanent population. Table 17 shows estimated total population levels for Westport and the surrounding area.

Table 17

WESTPORT WATER SERVICE AREA SEASONAL ESTIMATED POPULATION

	1990	2000
Permanent Residents	2,500	2,800
Seasonal Residents	4,200	5,000
Transients	26,000	28,000
Total	32,700	35,800
Peak Weekend Day	68,800	74,700

As is indicated, the peak weekend day population for the Westport Water Service Area can be more than 30 times the permanent population. This does not, however, translate to more than 30 times the water demand. While the South Beach area to the south of the Westport Water Service Area would experience a higher seasonal population, it is not expected to be on the same order as that shown in Table 17. A more specific estimate for unincorporated Grays Harbor County is not available due to lack of statistics such as wastewater treatment flows or water system metering data for use in evaluating increases in population. A further discussion of water usage is given later in this chapter.

3.4 Storm Water

3.4.1 City of Westport

The existing storm and surface water collection system in the City of Westport is comprised primarily of roadside ditches and culverts. There are a few streets and city right-of-ways that have structured surface water collection facilities. These are generally in the heavier developed commercial areas. There are small, isolated piping systems along Montesano from the city limits to Veteran Avenue. The central core (Ocean Avenue to Washington and Broadway to South Bay) of the city is also served by a localized collection system, as well as the Westhaven area.

The rest of the city primarily utilizes roadside ditches and culverts for the collection and transport of storm water. There are three major storm water ditch systems within the city limits. One is an open ditch system that runs north along North Forrest, adjacent to the Port of Grays Harbor property, then easterly and discharges via a floodgate near the north end of the airport. A main drainage channel runs north from Lake Cohassett, through the city's core, and daylights with an outfall and a floodgate near the easterly end of Elizabeth Avenue. This channel handles the surface water runoff collected from a substantial portion of the City.

A manmade wetland area is located in the vicinity of Dune Drive and Surf Street. Surface water from the immediate vicinity flows to the wetland during the wet season. As the wetland fills, it overflows to a ditch running north and ending near Ocean Avenue. With no outfall to a receiving water, the collected water ultimately evaporates off or percolates into the ground.

The surface soil on which the City of Westport is situated consists mostly of sand and sandy loam. Additionally, the city sits on a relatively level area with surface elevations ranging from sea level to 40 feet. Most of the occupied portions of the city are at elevation 15, or higher. This means that ground surface gradients are minimal. Therefore, generally only precipitation which falls on impervious surfaces, and not evaporating, will run off. Any precipitation falling on other improved surfaces such as lawns and gardens, generally evaporates or percolates into the soil, except during the heaviest storm events.

3.4.2 Grays Harbor County

The unincorporated area south of Westport lacks a formal surface water collection system for the most part. There is a large drainage channel that begins just north of Grayland and runs south past the Grays Harbor/Pacific County Line. Additionally, individual ditches surround cranberry bogs and also run along roadsides. While there is an eventual outlet to receiving waters in the Elk River delta area of South Bay, flow through the drainage system is very slow. The main channel appears to be undersized and clogged, causing localized flooding in some areas. While that fact is not critical to this study, it does indicate that a substantial amount of water may be available for groundwater recharge.

Because the South Beach area's storm water collection system is primarily an open ditch system, and available gradients are minimal to convey collected surface water to a receiving water by gravity, much of the water collected percolates into the ground. Most of the rainfall occurs during the wet season of September to April. Relative humidity remains high during this period, therefore evaporation has a minimal impact on surface water disposal. The percolating water eventually makes its way to the aquifer, thus replenishing the groundwater supply.

Investigations in the study area did not indicate any substantial use of dry wells or leaching beds for the disposal of storm and surface water. Individual buildings may use this type of facility, but it was not apparent that they are being used on an area basis.

3.5 Sewage Disposal

Within the City of Westport the vast majority of residents and businesses are connected to the Westport wastewater treatment plant for sewage collection, treatment, and disposal. While the entire city is covered by a network of sewage collection lines, there may be some isolated locations within the service area where on-site disposal systems are still used. The only

Westport Sewer System customers outside the city are the Twin Harbors State Park, the Hammond Trailer Park, and the Ocosta Elementary and Junior/Senior High School complex.

The significance of the Hammond Trailer Park connection is that is located in close proximity to the City's South Well Field. During design of a new sewage disposal system for the trailer park, groundwater levels were found to be high and directly influenced by the operation of the wells in the South Field. At that time it was determined to be in the best interest of all concerned to connect the trailer park to the Westport wastewater system. At this writing other residents and trailer parks in the South Field area outside the city limits are still using on-site systems for disposal of wastewater. The City has received several inquiries from residents of the area regarding connection to the City's sewer system. An interlocal agreement between the City of Westport and Grays Harbor County is not required to provide sewer service outside the city limits. However, such an agreement is recommended for cohesive planning purposes.

With the exceptions noted above, all other residences and businesses outside the City of Westport, use septic tanks and drainfields, or similar methods, for subsurface wastewater treatment and disposal. The 1991 Utilities Comprehensive Plan for Grays Harbor County[3] categorizes the soils in the South Beach area in three ways relative to use for on-site disposal.

Category 1 - Soil Suitable For Conventional System.
Category 2 - Soils With Limitations Which Will Require an Alternative System.
Category 3 - Unsuitable Soils.

Category 1 soils are described as being over 40 inches deep, well-drained, well structured and having adequate permeability to accept septic tank effluent. Category 1 soils within the study area are contained in a long, narrow shaped area starting near the center of Section 31, Township 16 N, Range 11 W, WM, just east of the Woodlane subdivision, at about mile post 28.4 on Highway 105, in unincorporated Grays Harbor and extending northerly to about Ocean Avenue in Westport. Where Category 1 soils cross highway 105, they are approximately 1/2 mile wide. Category 1 soils continue north past Jackson Street where they are approximately 3,600 feet wide, and end at roughly Ocean Avenue east of Montesano Street.

However, U.S.G.S. Quadrangle maps indicate that much of these same soils, listed as Category 1, are wooded marshes for their entire length south of approximately Jackson Street, which is located about seven blocks south of the Westport city limits at Highway 105 mile post 31 in unincorporated Grays Harbor County. Lake Cohassett, located outside of the wooded marsh, sits in Category 1 soils. Consideration should be given to reclassifying the wooded marsh area and Lake Cohassett area as Category 3 soils.

Field investigations verified the presence of the marsh, therefore rendering much of the area unsuitable for on-site disposal system use. Twin Harbors State Park occupies a portion of the designated Category 1 soils that exhibit wooded marsh characteristics. The park offers overnight camping facilities, both with and without hookups, which include power, water, and sanitary sewer connections. All site connections and restrooms in Twin Harbors State Park are connected to the Westport sewage collection system for wastewater treatment and disposal.

The soils map in the Utilities Comprehensive Plan[3] for the study area indicates that most of the soils fall into either Category 2 or Category 3. Category 2 soils are described as having "...soils which are too shallow, have a shallow restrictive layer, have a high water table, or are too rapid draining to meet standard rules for subsurface waste disposal." The Category 2 soils in the South Beach area appear to be Beach Sands, indicating rapid draining characteristics. This is the same soil type that the Westport wells are located in. The Category 2 soils cover most of the City of Westport, which is served by the wastewater treatment plant. South of Westport, Category 2 soils are found primarily seaward of SR-105. It would appear that most of the populated area south of Westport is situated on Category 3 soil.

The Utilities Comprehensive Plan[3] describes the Grayland area as follows: "The low-lying areas around Grayland are generally in Category 3 due to high water tables in sands. However, the soils to the west have characteristics suitable for treatment and disposal of wastewater. Wastewater disposal in this area must meet shoreline management requirements. Alternative methods of wastewater disposal may have to be considered to provide adequate groundwater protection." Nitrates are generally used as an early sign of potential contamination of groundwater as a result of on-site disposal practices. Well samples taken for the utility plan development showed the levels of nitrates to be well below drinking water standards of 10 mg/l (parts per million).

A Geographic Information System (GIS) map of the unincorporated Grays Harbor County south of Westport indicates that a substantial portion of the study area is platted. However, a majority of the platted lots shown are located north of SR-105 to the Westport City Limits and west of SR-105 down to the Pacific County line. Most of the platted lots lie on Category 2 soils, which can be used for on-site disposal with a properly designed treatment system. The remainder of the platted lots are located along Cranberry Road, and are used for the purpose of growing cranberries. This area is not amenable to substantial development.

The above discussion was based on a review of the Utilities Comprehensive Plan[3], other documents, and field investigations of the study area. It does not appear that any substantial development of the area, particularly east of SR-105 can take place without some sort of wastewater collection, treatment, and disposal system to serve such future developments. It may be possible for individual homes or small businesses to be developed on the basis of a case-by-case evaluation of the potential use of on-site disposal systems.

3.6 Water Use

3.6.1 City of Westport

The City of Westport's water system is comprised of six wells, two in the North Field and four in the South Field, two vertical tank standpipes for storage and gravity feed, and the distribution system. A third well in the North Field is presently inactive. Water is pumped from the wells to vertical storage tanks holding 2.1 million gallons. The height of the water in the storage tanks maintains a minimum hydraulic grade line and pressure throughout the system. The four South Field wells each have a capacity of 140 gallons per minute (gpm). The North Field well capacities are 250 gpm and 660 gpm. The total well capacity for the system is 1,470 gpm.

Water use in the City of Westport has been gradually increasing. Table 18 lists the water usage in the City's system from 1987 through 1992. As can be seen, usage has grown steadily, but does show a decline for 1991. The high water usage for the years of 1989 and 1990 can be attributed, in part, to outside, nonrecurring factors. The weather was cold during the winters and freezing did break some pipes and cause leaks. For February, 1989 alone, the City lost an estimated 5,000,000 gallons to leaks. The resultant repairs to the system could account for at least a portion of the drop in usage for 1991 in that some of the repairs were probably made on long term, previously undetected leaks.

July, 1992 water usage was the highest single month ever recorded at 28,184,000 gallons. The months of July and August are historically the heaviest usage months. This is primarily due to the greater influx of tourists during these two months. The heaviest day usage for "normal" purposes, that is strictly for domestic, commercial and industrial use, with no main flushing or firefighting needs, is generally on the Fourth of July or a weekend day in July or August. The 1992 Fourth of July population was estimated at over 60,000 people by City officials. This is more than 30 times the permanent population of Westport, and compares favorably with the estimate listed previously in Table 17.

Table 18
WESTPORT MONTHLY WATER USAGE
BY YEAR
Q x 1000

	1987 Total Volume	1987 Daily Avg	1987 High Day	1988 Total Volume	1988 Daily Avg	1988 High Day	1989 Total Volume	1989 Daily Avg	1989 High Day
Jan	14,460	466.452	856	15,786	509.226	681	15,573	502.355	820
Feb	11,542	412.214	589	14,252	491.448	835	24,245	865.893	1,645
Mar	13,122	423.290	629	14,905	480.806	838	18,472	595.871	1,151
Apr	14,888	496.267	727	19,006	633.533	1,013	23,675	789.167	1,288
May	19,154	617.871	876	19,139	617.387	942	22,764	734.323	1,228
June	21,241	708.033	983	19,717	657.233	1,135	21,091	703.033	967
July	25,238	814.129	1,203	25,438	820.581	1,167	20,757	669.581	922
Aug	25,443	820.742	1,193	24,126	778.258	1,142	23,945	772.419	1,048
Sept	20,761	692.033	959	18,749	624.697	1,287	21,700	723.333	948
Oct	18,792	606.194	807	19,485	628.548	1,313	16,920	545.806	756
Nov	13,843	461.433	725	12,442	414.733	562	15,353	511.767	1,067
Dec	16,172	521.677	816	14,503	467.839	755	15,926	513.742	902
	------	-------		------	-------		------	-------	
Total	214,656	588.099		217,548	594.393		240,420	658.688	

	1990 Total Volume	1990 Daily Avg	1990 High Day	1991 Total Volume	1991 Daily Avg	1991 High Day	1992 Total Volume	1992 Daily Avg	1992 High Day
Jan	18,468	595.742	858	16,443	530.419	673	14,496	467.613	762
Feb	16,372	584.714	914	13,020	448.966	615	12,653	436.310	573
Mar	19,833	639.774	1,015	14,345	462.742	618	15,556	501.806	947
Apr	17,660	588.667	747	16,030	534.333	782	19,529	650.967	1,099
May	22,939	739.968	1,157	18,978	612.194	907	19,067	625.065	913
June	21,706	723.533	959	17,279	575.967	713	21,540	718.000	1,036
July	24,570	792.581	1,010	22,637	730.226	1,358	28,184	909.161	1,172
Aug	23,574	760.452	976	21,199	683.839	871	26,352	850.065	1,268
Sept	18,916	630.533	955	19,410	647.000	970	20,070	669.000	922
Oct	16,362	527.806	789	19,386	625.355	904	18,746	604.710	1,075
Nov	11,603	386.767	582	11,366	378.867	556	13,388	446.267	807
Dec	19,625	633.065	1,358	12,102	390.387	598	15,465	498.871	725
	------	-------		------	-------		------	-------	
Total	231,628	634.597		202,195	552.445		225,046	614.880	

Water use is generally a function of the population of the service area. Other influences on usage will be commercial and/or industrial, and as in the case of Westport, transient, or tourist population. Westport has a substantial commercial/industrial water user base. Westport could be considered an anomaly for cities of its size. Its orientation with the ocean has created a relatively large base for commercial/industrial enterprises, including seafood processors and hotel/motels, that consume large amounts of water. Total water usage for these customers is approximately two thirds of the total produced by the city. The fish processing water customers alone use approximately 32% of the total. Table 19 shows the 1992 water usage by the largest commercial/industrial customers. It does not include apartments or mobile home parks which are considered as commercial customers under Westport's billing system.

Table 19
1992 COMMERCIAL/INDUSTRIAL WATER USAGE

Name	Consumption (gal)
Washington Crab	62,592,640
Other Fish Processors	9,641,720
Wastewater Treatment Plant	2,834,920
Port of Grays Harbor	9,073,240
Islander Motel	2,730,200
Westport Chateau	3,059,320
Twin Harbors State Park	1,840,080
Ocosta Schools	1,742,840
U.S. Coast Guard	6,874,120
TOTAL	100,389,080

The lowest monthly water use for 1991 was in November. This month also coincides with the period of lowest tourist activity in the City. Evaluation of November's water use against permanent population figures, after deducting 67% for commercial/industrial usage, results in a 66 gallons per capita per day usage. This is just below the use range of 70 - 100 gallons per capita per day generally recognized as normal, outside of lawn and garden watering.

Additional new water usage will result from increased permanent population, increased tourist facilities (destination resort), and new industries (fish farm). From Table 17, by the year 2000 permanent population could increase Westport Water System use by 21,000 to 30,000 gallons per day total, based on a 70 to 100 gallon per day per capita usage range. The destination resort and convention center will have a substantial impact on water use by the fact of increasing day-to-day population, even if it is not permanent.

One of the largest impact from the resort could come from the need to irrigate the new golf course. Other alternative sources, such as recycled wastewater are being investigated. Another large impact may be in the offing. Washington Crab has expressed a serious interest in modifying its operations to include processing pollack and hake into "faux crab." If this comes to pass, it will increase their water usage by a factor of up to five. Presently they use approximately 170,000 gpd, based on 1992 figures. A factor of five would bring their use to over 850,000 gpd. Presently, the city does not have the resources to provide that amount of water. If the fish farming operation becomes a reality, the average additional need may be as high as 1,125 gallons per minute (gpm)[6]. While this additional need will only be for approximately a two month period twice a year, it represents a potentially serious impact to groundwater supplies during the non-recharge period.

Concurrent with this project, the city completed a new Comprehensive Water System Plan. As required by the Washington State Department of Health (DOH), a Water Conservation Program was also developed. Implementation of the conservation plan is required. However, it only projects a ten percent savings in present water production requirements over the next 4-6 years. This savings will not be enough to offset all the increased needs discussed here. Additional sources of supply will be required.

3.6.2 Grayland

The Community of Grayland is served by Grays Harbor County Water District No. 1 (GHCWD No.1). The service area extends from the Grays Harbor/Pacific County line north along State Highway 105 almost three miles to Woodlane Estates. The district has two wells located just across the county line in Pacific County. One well of 350 gpm capacity provides primary service. The second well at 150 gpm is generally used only in emergencies. Unlike Westport with its gravity system, the District uses booster pumps to maintain system pressure.

The Water Facilities Inventory form, filled out in July, 1992, for the Washington State Department of Health shows a total of 575 customers and 350,000 gallons of storage capacity. The district reports that it uses 100,000 gpd during the winter, and 160 - 220,000 gpd average to peak use during the summer. There is not the commercial/industrial base in Grayland as exists in Westport. The average per customer winter usage is 174 gpd, while the summer average per customer usage range is 278 to 381 gallons per customer per day. If the household population is 2.3 to 2.5 people per residence, the winter per capita usage would range from 76 to 70 gallons respectively. This equates very well with the usage factor found in Westport.

The Grayland area does not have a large commercial/industrial base, nor does it experience the high concentration of daily tourists that Westport does. However, the area does contain some small resort motels and restaurants. This additional requirement could account for the high per customer summer usage, since residences in the Grayland area do not appear to use a lot of water for lawn or family garden sprinkling. A breakdown between residential and other uses is not available.

Cranberry crop irrigation is generally done with individual wells on each farm. While this may not have an impact on individual public water system usage, it could have an effect on use of the aquifer. The Washington State Department of Ecology has records for eight (8) wells in the Sections of Township 15N Range 11W, WM which are included in this study. Four of the eight are still in the application stage as of the date of record, June 25, 1993. Of the eight, only two are for irrigation purposes. One is a certified water right and the other is still in the application stage.

Two of the eight wells are limited to Domestic use. Two are for Domestic Multiple Use. The one certified Domestic Multiple Use well is limited to 12 gpm, but 19.2 acre-feet can be extracted. This well could be used for irrigation, also. The other Domestic Multiple Use well is still in the application stage, but 200 gpm has been requested. The two remaining wells are for Multiple Use. The one certified is for 100 gpm and 8.5 acre-feet. This well could be used for irrigation. The other Multiple Use well is in the application stage, and is only for 10 gpm. This well probably will not be used for irrigation, unless it can sustain this flow on a 24-hour basis.

3.6.3 Private Water Companies

There are three private (investor owned) water companies between the service areas of the City of Westport and Grays Harbor County Water District No. 1. Each of the companies serves a residential development within a limited service area. They are the Slenes Water Company (Surfside Resort), the Wind Sand Water Company, and the Sand and Surf Water Company. While they are situated within the area covered by an interlocal agency agreement, they are not in conflict with either the City of Westport or GHCWD No.1, because these systems are privately owned. Two of the companies have a water quality problem. The quality problems are different for each.

3.6.3.1 Slenes Water Company (Surfside Resort)

The Slenes Water Company began as a small water system to serve a motel. The system gradually expanded to serve approximately 65 customers, most of whom are permanent as opposed to seasonal. The original owner died, and the motel and water company have been purchased by a new owner. He changed the name of the water system to the Surfside Resort Water Company. The Surfside Resort Water Company serves the area of Bonge Avenue, from SR-105 to the ocean beach, and also a small area across SR-105 from Bonge Avenue. The company uses an old, abandoned oil well test hole for its source of water. The well was drilled by Continental Oil in 1951.

The well is a 5-inch diameter casing 1,400' deep. The Water Well Report states sand exists to 100' with shales to 147'. No water bearing strata was revealed past 147'. Static water level was reported at 16' below the top of casing. The system uses a 3/4 hp submersible pump set at approximately 80' below the ground surface. The casing is apparently not perforated, so the source of the water is the bottom of the casing. Therefore, the water is assumed to be from the deep aquifer in the South Beach area. The pump sends water to a 17,000 gallon, open concrete settling tank. The water is prechlorinated as it is pumped from the well.

Apparently residual oil from the casing appears in the water periodically. Although it has not been heavy enough to cause a health problem, it is disconcerting to the customers to have a slight oily smell or taste to the water. Because of the company's inability to overcome the problems, the State has taken over the system. They have retained Culligan to install and operate a treatment facility for the water before it enters the distribution system. Surfside uses a pressure tank to maintain system pressure, and operates on a pressure of 50-62 psi. After the treatment system installation, they reported that they were getting good quality water.

The Surfside Water Company has 65 customers with little or no seasonal fluctuation. The system does not provide fireflow. The company has made some inquiries about the City taking over the system.

The foregoing is a description of the Surfside Water System as it was at the beginning of the of this project. In March, 1993 Surfside Water Company experienced serious problems with their supply that the new treatment facilities could not handle. An imminent risk letter was written by DOH. Because of the problems, Westport was asked by the DOH if they could supply water to the troubled company. In May, 1993 during delays for obtaining grant funding for emergency installation of the water system extension, the water from the well cleared up. The imminent risk threat was removed. The extension was not constructed at that time. However, in July, 1993, the well went down again. Because of past problems, it was determined that a permanent fix could not be made.

The City was able to obtain emergency funding to extend its system approximately 3,000' south to Bonge Avenue. In September, 1993 a connection was made to the Surfside system through a 4-inch master meter. This provided temporary water service to Surfside, which in turn then provided water to its customers. The citizens served by this water company petitioned Grays Harbor County to form a Utility Local Improvement District (ULID) to upgrade the water system. If approved, a new distribution system will be constructed by the City. Completion of the new water distribution system should be accomplished in 1994. The system will be turned over to the City upon completion of improvements to bring it up to City standards.

3.6.3.2 Wind Sand Water Company

The Wind Sand Water Company is also privately owned and serves the Wind Sand Estates residential development, located approximately 1/2 mile south of Twin Harbors State Park on the west side of SR-105. The streets served are Wind Sand Lane and Cabin Lane. They presently have 25 customers, nine of which are permanent, year-round residents. The remaining customers are seasonal. Their water quality problems are associated with high iron and manganese in the source.

The well is approximately 254' deep, and apparently withdraws water from the deeper aquifer. The pump is set at 50' below the ground surface. They have installed a filtration system to remove the iron and manganese. There are two filters, each of five gpm capacity. This has caused them to restrict the well pump from 26 gpm to 10 gpm output. The reduction in flow has created a concern on the company's part regarding potential high pressures in the pump discharge line.

The well water is prechlorinated using HTH dry chlorine and discharges to a 5,000 gallon open top concrete holding tank. Chlorination assists in settling out the manganese in the tank. The water quality has been relatively good during low use periods. The settled manganese is not discharged to the distribution system. Because their storage tank is small, it does not provide volume for proper year-round service at the restricted well pump rate.

Pressure in the system is maintained in the system at a range of 40-60 psi by the use of a pressure tank. The distribution system is only 2-inch diameter PVC, so cannot provide for fireflow needs. They have expressed an interest in the possibility of connecting to the City of Westport's water system. For that to occur, it will be necessary to amend the interlocal agency agreement, because Wind Sand Estates is located south of Bonge Avenue, in the GHCWD No. 1 service area by the existing agreement.

3.6.3.3 Sand and Surf Water Company

This system is located along the west side of SR-105, between Surfside and Wind Sand Water Companies. Like Wind Sand, this is a small water system serving up to 25 customers. There are four or five permanent, year around connections to the system. The remaining hookups are of a temporary nature including cabins and RV sites. The owner could not be contacted for additional specifics on the system. However, it is understood that the health department will not let the owner expand the recreational facilities because of sanitary control problems (too close to the well and/or no sanitary sewers). If the owner wishes to expand, she may want to connect to the Westport water system.

IV. SURFACE ACTIVITY IMPACTS

4.1 Population

Table 17 indicates that the population of the Westport and South Beach area will continue to grow. Present growth rates appear to be substantially above that of Grays Harbor as a whole. New commercial/industrial enterprise information requests indicate that Westport may be able to provide a more stable employment picture, ensuring that the permanent population will continue to grow. Additionally, Westport tourism seems to be increasing rapidly also, in spite of the reduction in available salmon fishing season length. All of this means that the entire area including South Beach will require additional water resources.

An increasing population and new commercial/industrial enterprises will bring additional potentially adverse impacts in other areas such as storm drainage, on-site sewage disposal, spills, and underground storage facilities. Each of these is discussed in the following subsections.

4.2 Storm Water

Storm and surface water, in and of itself, will not have an adverse impact on the quality of the water in the aquifer. It is the constituents of the surface water runoff that have the potential for creating problems. Street surface runoff, for example, contains high levels of total petroleum hydrocrbons (TPH's), copper, and zinc. It is the extraneous material that is picked up by runoff or is discharged to the drainage system that will create problems. In areas where unleaded gasoline use is high, lead is also found in the runoff. If people dump waste oil into catch basins, it is highly likely, that given the nature and configuration of the drainage systems serving Westport and the South Beach area, that a portion of the oil will percolate into the soil column.

Because of the topography and geology in the Westport and South Beach area, high quantity run off during storm events is generally not a problem. Much of the storm water runoff percolates directly into the soil. With that in mind, the geology can be a problem in the Category 2, rapid draining, soils. If high levels of fertilizers, herbicides, and pesticides are used, they could potentially leach into the aquifer. Up to now that does not seem to be a problem. Measures should be taken to prevent future contamination of the aquifer.

4.3 On-Site Wastewater Disposal

Category 2 soils could allow pollutants to reach groundwater relatively undiminished if the soil is excessively drained, and no intervening layer of "tight" soils are present. Tight soils would impede the downward progress of the wastewater, and provide either filtration or detention to allow microbial reduction or elimination of pollutants. From soil maps and observations in the Hammond Trailer Park area, an absence of tight soils or an intervening layer could be the situation for the unincorporated area immediately south of Westport, in the vicinity of the City's

South Well Field. If so, contamination of the South Field is a possibility, particularly if additional well pumping capacity is required at this site.

On-site disposal of wastewater in the area of the Grays Harbor County Water District No. 1 wells should be less of a problem than in Westport. The reasons are twofold. First, the area around the wells is considerably less developed. There are cranberry farms and a few single family dwellings near the wells, but not to the degree as in Westport. Second the type of soils the disposal systems are constructed in are Category 3. The Utilities Comprehensive Plan for Grays Harbor County[3] shows the Category 3 soils down to the Pacific County line in the area the wells are located in. Field investigations confirm that this type of soil extends south of the well site. These soils provide a higher retentive capacity, and therefore more time to provide biological treatment of the wastewater. Additionally, these soils are tighter, with smaller pore space, and provide better filtering of the wastewater.

4.4 Spills

Spills of hazardous or toxic materials are generally the result of human error. Sometimes a mechanical failure will be the cause. However, more often than not, it is human error. For the South Beach area, and Westport in particular, a spill above the aquifer would most likely be the result of a traffic accident involving a tank truck hauling fuel. The fleet of boats moored at Westhaven requires a considerable amount of fuel, as well as the motor vehicles, both permanent and transient, in the Westport area.

Because of the restricted speed limits in most of the area, a catastrophic spill of a large volume of fuel or other such material is less likely. For this report, a catastrophic spill is considered to be most of the contents of one of the tanks of a semi-truck and trailer rig. This type of spill generally happens when a pipe or fitting on the tank is completely sheared off, and the discharge of tank contents cannot be controlled.

Another possibility for a spill is when a tank truck is refilling an underground storage tank either at a fueling facility for boats, or an automobile service station. These types of spills are generally due to inattention on the part of the truck driver. A large spill can occur if a hose becomes disconnected or the truck's safety shutoff device doesn't work properly, and the driver is not paying attention. There have been instances in other cities where several thousands of gallons have been spilled before a problem was noticed.

Neither the City of Westport nor Grays Harbor County are well equipped to control, contain, and clean up a major spill of toxic or hazardous materials. In most jurisdictions, the local fire department has the primary responsibility of responding to such incidences. In Wesport and the unincorporated Grays Harbor County, the Fire Department is not equipped to properly contain and remove spilled hazardous material. While the U.S. Coast Guard is stationed in Westport, its primary role in hazardous material spills is that the spilled material does not reach "navigable waters." They would not be responsive for spills that are contained on land.

4.5 Underground Storage Tanks

The highest potential for hazardous or toxic material moving into the soil column in the South Beach area is from a leaking underground storage tank. This has already occurred in the past at the Hungry Whale service station located at the corner of Forrest (Wilson) and Montesano. A leak of unleaded gasoline was discovered in 1985. Apparently it was not reported to the Department of Ecology until 1991. Ecology undertook a remedial action plan to clean up the area, but to date it has not been completed. It is reported that product can still be found in one to two feet of the soil column as deep as 20'.

The specifics of the situation were not clear until after the new monitoring wells and computer modelling were completed. Therefore, a complete analysis of the potential problem was not carried out. Based on a review of the existing model report, it appears that the city could have a future problem with the gasoline in the soil.

The Hungry Whale is approximately one half mile from North Field Well No. 3. Figure 27 shows the "capture zone" for the existing North Field Well No. 2. The heavy dashed line indicates the capture zone area. It appears as if the Hungry Whale may be on the cusp, if not actually in the zone. The remaining product in the soil column could be slowly migrating towards the North Well Field.

V. RECOMMENDATIONS

5.1 Hydrogeologic Recommendations

The aquifer system at Westport is totally dependant upon local precipitation and very vulnerable to contamination from salt water intrusion or other causes. The continued production of high quality water at Westport depends upon efficient monitoring and management of the ground water resource. The incomplete monitoring practices used in the past could cause a failure to forecast serious water quantity and quality problems in the future. To help prevent future problems the following recommendations are made:

- The City should use the following wells in a water level monitoring network, with accurate measurements made by sounder or transducer at the minimum frequencies listed below:

  A. All production wells, weekly or semimonthly
  B. Monitor Wells 1, 2, and 3, semimonthly
  C. Quality Control Wells 1 and 2, semimonthly
  D. New South Field monitoring well recommended below, semimonthly
  E. Roberts Farm monitoring wells (if site is developed), semimonthly
  F. Monitor Wells 4 and 5, quarterly

- To complete the monitoring network, the City should place the original South Field observation well (Ref. No. 141) into the network. If this well no longer exists, an alternate well on the east side of the well field should be found or drilled.

- The network should be monitored for water quality as listed below:

  A. Monitor Wells 1, 2, and 3, quarterly
  B. Quality Control Wells 1 and 2, both peizometers, quarterly
  C. New South Field monitoring well (see above), quarterly
  D. Roberts Farm monitoring well (if the site is developed), quarterly
  E. Monitoring Wells 4 and 5, annually

- The City currently lacks sufficient instantaneous water rights. The quickest way to correct this deficiency is to bring North Well 3 on line. This will allow the water right for Well 3 to become certificated.

- Overall production should be reduced at the North Field. The recommended maximum annual production during severe droughts is 100 million gallons. Production reductions at the North Field can partially be made up by an increase at the South Field.

- Annual production at the South Field can be increased above typical recent values, which have averaged 65 million gallons. The recommended maximum annual production during severe droughts is 90 million gallons.

- Until a new source can be developed, the City should closely monitor and manage production from the well fields. Emergency plans should be established to encourage additional conservation (beyond the standard conservation plan) and reduce production if salt water intrusion appears likely. If static water levels at the well fields fall below sea level, production should be reduced. Monitoring of precipitation and estimated recharge is highly recommended. Lower than normal October through March values should forewarn of possible summer water shortages.

- A new source needs to be developed. On the peninsula, a new well field is recommended half way between the present fields, in the vicinity of Hancock and Forrest. The field should be developed with two or more wells to spread out the effects on ground water system.

- Additional water is also available by developing aquifers in the Satsop Formation. The best known location for this is at Roberts Farm, where up to 1000 gpm may be available. However, additional testing at the site is needed if large production is to occur at the site. Ideally, a well field at this location will have three or more widely spaced production wells and three monitoring wells. Monitor wells should be located on the South Bay side of the production wells. One of these should monitor the production zone, the other two should be completed in shallower deposits.

- A post-audit of the numerical model should be performed after two to five years of monitoring network and production data have been collected. The post-audit will allow for a re-assessment of the model predictions. If the post-audit reveals the model to be significantly in error, the model can be recalibrated with the new data and revised production limits created. Recalibration is also recommended if a new well field is developed on the peninsula. This post-audit will require the data collected from the monitoring network.

- The Westport aquifer is very vulnerable to salt water intrusion and other contamination. A wellhead protection study, including an inventory of potential contamination sites should be performed to better assess current and future risks to the aquifer. As part of this study, capture zones and recharge areas for the well fields should be better defined.

5.2 Surface Activity Control Recommendations

Because Westport and South Beach rely solely on ground water for their sources of potable water, control of surface activities that may impair those sources is imperative. Although the recommendations made here will add to the operating expenses of the City of Westport and Grays harbor County, the cost of developing alternative sources such as surfce water will be extremely expensive. On that basis the following recommendations are made:

- The Hydrogeologic Recommendations included a wellhead protection program. This study should include Grays Harbor County, because of the unincorporated area locations of the existing South Field wells and the possibility of developing a new well field in the vicinity of Roberts Farm. Both areas are outside the corporate limits of Westport.

- The city and county should develop a joint Storm and Surface Water Management Program to handle storm and surface water runoff so as to mitigate potential adverse impacts to the aquifer(s). While there have been no apparent problems to date, unless some process is put into place, potential contamination is always a threat, given the geology of the Beach Deposits.

- At a minimum, the City of Westport should consider development and adoption of a "Storm Drain Utility." The county should also consider forming a similar utility for the unincorporated South Beach area. Such a utility would enable the city and/or county to fund the Storm and Surface Water Management Program.

  Additionally, the city could fund a system of closed storm drains to collect the street runoff from its busiest streets. This runoff has the highest incidence of contaminants.

- The city now requires all new buildings constructed within the city limits to connect to the sanitary sewer system. The county should encourage all new similar construction to connect to sewer whenever it is reasonable. The county should also encourage the formation of Utility Local Improvement Districts (ULID's) for sewer service for existing buildings. This is particularly true in the area between the city limits of Westport and Twin Harbors State Park. The proximity of the aquifer for the South Field to the ground surface could allow contamination by discharges from on-site disposal systems.

- The City and County Fire Departments should develop an "Action Plan" for responding to spill incidences, especially those which involve toxic or hazardous material. Spill prevention and response training should be required for all fire Department and Public Works personnel. Additionally, an inventory of spill containment and removal equipment and material should be maintained at a ready state to respond as soon as possible to spills. Those areas over the Beach Deposits are especially vulnerable to wide spread contamination due to a spill. This is particularly true if the spilled material is something like gasoline. It would percolate downward at a rapid rate and may not be fully recoverable if a response to the spill is hampered in any way.

- The situation with the gasoline product in the soil column around the hungry Whale sservice station should be resolved immediately. In order to protect the North Well Field, the city should install a new monitoring well approximately halfway between the service station and the North Well Field. It should be sampled on a regular basis, but more frequently in the summer during peak use periods.

  In addition, the city should petition Ecology for an immediate response to the total clean up of the area. This situation will continue to pose a threat to the city's potable water source until the product is completely removed.

This situation provides an even stronger reason for pursuing the additional recommended well in the vicinity of Forrest and Hancock. Also, changing the pumping controls as soon as possible to those recommended above to better utilize the South Field is highly recommended.

- Both the city and the county should work closely with the Washington State Department of Ecology to obtain and maintain an inventory of underground storage tanks in Westport and South Beach. A record of each and every tank should be kept on hand in local files, along with the amount and type of material stored. Regular testing results should be also be maintained. Both agencies should have written assurances from the owners of the tanks they properly maintain the tanks and know how to respond in case a leak is discovered.

HYDROGEOLOGIC REFERENCES

Anderson, M.P., and Woessner, W.W., 1992, *Applied groundwater modeling, simulation of flow and advective transport:* San Diego, Academic Press, 381 p.

McDonald, M.G., and Harbaugh, A.W., 1988, *A modular three-dimensional finite-difference ground-water flow mode:* U.S. Geological Survey Techniques of Water-Resource Investigations Book 6, Chapter A1, 586 p.

Rumbaugh, J.O., 1993, *ModelCad*^{386}. Reston, VA, Geraghty & Miller, Inc., 196 p.

Tracy, J.V., 1978, *Ground-water resources of the North Beach Peninsula, Pacific County, Washington:* U.S. Geological Survey Open-File Report 77-647, 45 p.

Wegner, D.E., 1956, *Preliminary investigation of ground water in the Grayland Watershed, Grays Harbor and Pacific Counties, Washington:* U.S. Geological Survey Open-File Report, 32 p.

Hantzsch, N.N., and Finnemore, E.J., 1992, *Predicting ground-water nitrate-nitrogen impacts:* Ground Water, Vol. 30, No. 4, p. 490-499

Dion, N.P., and Sumioka, S.S., 1984, *Seawater intrusion into coastal aquifers in Washington, 1978:* Washington Department of Ecology Water-Supply Bulletin 56, 14 plates

Foxworthy, B.L., and Walter, K.L., 1971, *Description of a test-observation well near Westport, Grays Harbor County, Washington:* Washington Department of Ecology and U.S. Geological Survey Water Resources Division, 30 p.

Newcomb, R.C., 1947, *Ground water of the South-Bar Area, Grays Harbor, Washington:* U.S. Geological Survey Open-File Report, 12 p.

SURFACE ACTIVITY REFERENCES

1. Grays Harbor Regional Planning Commission; *City of Westport Comprehensive Plan*, 1986

2. Moore, Wallace, & Kennedy; *City of Westport Water System Plan*, Revised March, 1984

3. Parametrix, Inc., et al; *Utilities Comprehensive Plan, Grays Harbor County*, October, 1991

4. Grays Harbor Regional Planning Commission; *City of Westport, Preliminary Classification and Designation of Natural Resource Lands and Critical Areas*, March 13, 1992

5. Foxworthy, B. L., and Waters, K. L.; *Description of a Test-Observation Well near Westport, Grays Harbor, Washington*, January, 1971

6. Noble, John B.; *Personal Communication: Availability of Ground Water Supply for Proposed Fish Rearing Operation*, August 28, 1986

APPENDICES

APPENDIX 1

WESTPORT PRODUCTION DATA

Westport Production Data

	Monthly Totals in Thousands of Gallons				Annual Totals in MG				
Date	North 1	North 2	South Field	Total	North 1	North 2	North	South	Total
Jan-86	0	8673	2712	11385					
Feb-86	0	3446	8182	11628					
Mar-86	0	1731	11798	13529					
Apr-86	0	5997	9021	15018					
May-86	0	9814	7265	17079					
Jun-86	0	7644	11912	19556					
Jul-86	0	9211	11591	20802					
Aug-86	4197	14260	6702	25159					
Sep-86	4141	7993	6500	18634					
Oct-86	5231	4434	6518	16183					
Nov-86	3305	1826	6373	11504					
Dec-86	3565	3040	6941	13546	20.439	78.069	98.508	95.515	194.023
Jan-87	3311	3715	7434	14460					
Feb-87	5140	1957	4445	11542					
Mar-87	4890	3922	4310	13122					
Apr-87	4632	7436	2820	14888					
May-87	3803	5443	9908	19154					
Jun-87	4471	15248	1522	21241					
Jul-87	4332	17673	3233	25238					
Aug-87	3287	10623	11533	25443					
Sep-87	6245	4916	9600	20761					
Oct-87	6603	3590	8599	18792					
Nov-87	3912	2011	7920	13843					
Dec-87	4398	3466	8308	16172	55.024	80	135.024	79.632	214.656
Jan-88	6341	5972	3473	15786					
Feb-88	6353	5634	2265	14252					
Mar-88	6402	7396	1107	14905					
Apr-88	5667	11278	2061	19006					
May-88	6357	7740	5042	19139					
Jun-88	5544	6677	7496	19717					
Jul-88	5279	14800	5359	25438					
Aug-88	6231	12261	5634	24126					
Sep-88	3898	13398	1453	18749					
Oct-88	4658	13768	1059	19485					
Nov-88	3834	8152	456	12442					
Dec-88	6028	6589	1886	14503	66.592	113.665	180.257	37.291	217.548

Westport Production Data

Date	Monthly Totals in Thousands of Gallons North 1	North 2	South Field	Total	Annual Totals in MG North 1	North 2	North	South	Total
Jan-89	5872	7973	1728	15573					
Feb-89	4043	17691	1807	23541					
Mar-89	6996	7678	3798	18472					
Apr-89	4902	17650	1123	23675					
May-89	3304	19131	329	22764					
Jun-89	3478	11537	6076	21091					
Jul-89	3094	12126	5537	20757					
Aug-89	4438	12534	6973	23945					
Sep-89	4417	9915	7368	21700					
Oct-89	1113	15807	0	16920					
Nov-89	4067	11286	0	15353					
Dec-89	4064	11862	0	15926	49.788	155.19	204.978	34.739	239.717
Jan-90	4415	14053	0	18468					
Feb-90	4735	6804	4833	16372					
Mar-90	4527	11212	4094	19833					
Apr-90	3078	9069	5513	17660					
May-90	3337	14593	5009	22939					
Jun-90	1850	15078	4778	21706					
Jul-90	1978	16670	5922	24570					
Aug-90	3319	9558	10697	23574					
Sep-90	4089	9715	5112	18916					
Oct-90	4781	5280	6301	16362					
Nov-90	1780	1326	8497	11603					
Dec-90	2154	7063	10408	19625	40.043	120.421	160.464	71.164	231.628
Jan-91	3857	6561	6025	16443					
Feb-91	1723	5195	6102	13020					
Mar-91	5785	4640	3920	14345					
Apr-91	5543	4205	6282	16030					
May-91	3059	6820	9099	18978					
Jun-91	4999	5913	6367	17279					
Jul-91	5201	10830	6606	22637					
Aug-91	5516	10743	4940	21199					
Sep-91	4822	9770	4818	19410					
Oct-91	5344	7765	6277	19386					
Nov-91	3782	3436	4148	11366					
Dec-91	1142	5194	5766	12102	50.773	81.072	131.845	70.35	202.195

APPENDIX 2

WESTPORT DEPTH TO WATER
AND
WATER LEVEL ELEVATIONS

Westport Depth to Water Measurements

	#38 North #1	#125 North TW #1	#127 North #2	#126 North TW #2	#37 North #3	#5 South #1	#6 South #2	#7 South #3	#4 South #4	#128 Lighthouse QC-1(WQ-2) shallow (E)	deep (W)	#129 Airport QC-2(WQ-1) shallow (S)	deep (N)	#136 MW1	#137 MW2	#138 MW3	#8 Old South 1	#2 Old South 2	#1 Old South 3	#141 Old South Obs. Well	#135 Old South Test Well	#142 Peterson	#134 elev. esti Twin Har
02/10/49																					21.08		
03/01/49																	24.9				20.88	0.87	
04/15/49																	25.9	24.1	25.9	8.19	21.78	1.47	
06/15/49																	27.3	25.4	27.4	8.89	23.08	2.27	
08/15/49																	30.1	28.8	30.8	10.79	25.98	3.37	
10/15/49																	30.2	27.6		11.39	25.68	4.47	
07/28/70																							2.92
07/27/71		8																					
01/17/72	11.1																						
04/11/74				10.4																			
12/06/76			10.25	13.6						21	23.2	7.8	8.2										
08/12/77				14.4						20.5	23.4	8.4	8.6										
Nov-82	13.5		9.5																				
Jan-83	12.5		7.5																				
Mar-83	13.5		10.5																				
May-83	15.5		11																				
Jul-83	16.5		11.5																				
07/06/83								26.1															
07/13/83									26.9														
Sep-83	16.5		12.5																				
Oct-83								27	27.5														
Nov-83	13.5		9.5					25.5	26.5														
Jan-84	14.5		8.5					25	25.5														
Mar-84	14.5							25	25.5														
03/06/84							23																
03/12/84						23.4	22.95																
Apr-84	16		11					27.5	28														
May-84	14		10.5			24.5	24	26.5	26.5														
Jun-84	15.5		11.5			26.5	25.5	26.5	26.5														
Jul-84	16.5		11.5			26.5	26	26.5	27.5														
Aug-84	16.5		11.5			28.5	27.5	27.5	28.5														
Sep-84	16.5		11.5			29.5	28.5	29	29														
Oct-84	17.5		12.5			30	29	29	29														
Nov-84	13		10			27.5	26.5	28	29														
Dec-84	14		9			24.5	24.5	36	27														
Feb-85	15.5		10.5			26.5	26.5	26	26.5														
Apr-85	16.5		18.5			28	27	26	27														
May-85	15.5		17.5			31.5	26.5	26	26.5														
Jun-85	16.5		12			30.5	27	28	25.5														
Jul-85	15		14			27	28	27.5	29														
07/23/85	17.5		13			29.5	28	27.5	27.5														
08/12/85						31.5	31	29	28														
09/03/85	15.5		14			31.5	30.5	29.5	30.5														
10/02/85	17		12			31	31.5	29	29.5														
11/07/85	14.5		10			28.5	27	27.5	27.5														
12/04/85			11			28	27.5	26.5	27														
Feb-86			11.5			28	26.5	25	27														
04/02/86			9.5			27.5	26.5	25.5															
05/05/86			10.5																				
05/08/86						25.5	23.5	24	26.5														
06/03/86			11.5			28.5	25.5	25.5	27														
08/07/86	16.5		12			27.5	26.5	27.5															
03/12/87					5																		
05/04/93														5.62	4.72	6.02							
07/06/93														7.76	6.3	8.38							
07/14/93	16.6		11.8			26.9	26.6	26	26.8	19.7	22.8	7.7	8										
08/16/93	17.5		12.9			28.8	28	29.3	30.6														
10/06/93	19		12.8			29.1	29.1	31.5	31.1														
10/20/93	17.21		12.68	14.35	9.52	29.22	28.86			21.5	23.75	7.59	7.84	8.52	6.72	10.43							
10/22/93	17.2		12.8			29.2	28.6	29.8	30.7														

Westport Water Level Elevations

	#36	#125	#127	#126	#37	#5	#6	#7	#4	#128 Lighthouse QC-1(WQ-2 elevations estimated		#129 Airport QC-2(WQ-1)		#136	#137	#138	#8	#2	#1	#141	#135	#142	#134
	North #1	North TW #1	North #2	North TW #2	North #3	South #1	South #2	South #3	South #4	shallow (E)	deep (W)	shallow (S)	deep (N)	MW1	MW2	MW3	Old South 1	Old South 2	Old South 3	Old South Obs. Well	Old South Test Well	Peterson	elev. esti Twin Har
MP Elevatio	19.5	13.97	15.17	17.45	12.16	34.3	33.15	34.06	35.65	26.26	27.85	10.66	10.87	10.12	9.58	13.72	35.1	33.1	34.8	15.69	30.86	8.67	10
10-Feb-49																					9.8		
01-Mar-49																	10.2				10	7.8	
15-Apr-49																	9.2	9	8.9	7.5	9.1	7.2	
15-Jun-49																	7.8	7.7	7.4	6.8	7.8	6.4	
15-Aug-49																	5	4.3	4	4.9	4.9	5.3	
15-Oct-49																	4.9	5.5		4.3	5.2	4.2	
28-Jul-70																							7.06
27-Jul-71		5.97																					
17-Jan-72	8.4																						
11-Apr-74				7.05																			
06-Dec-76			4.92	3.65						5.26	4.65	2.86	2.67										
12-Aug-77				3.05						5.76	4.45	2.26	2.27										
01-Nov-82	6		5.67																				
01-Jan-83	7		7.67																				
01-Mar-83	6		4.67																				
01-May-83	4		4.17																				
01-Jul-83	3		3.67																				
06-Jul-83								7.96															
13-Jul-83									8.95														
01-Sep-83	3		2.67																				
01-Oct-83								7.06	8.35														
01-Nov-83	6		5.67					8.56	9.35														
01-Jan-84	5		6.67					9.06	10.35														
01-Mar-84	5							9.06	10.35														
06-Mar-84							10.15																
12-Mar-84						10.9	10.2																
01-Apr-84	3.5		4.17					8.56	7.85														
01-May-84	5.5		4.67			9.8	9.15	7.56	9.35														
01-Jun-84	4		3.67			7.8	7.65	7.56	9.35														
01-Jul-84	3		3.67			7.8	7.15	7.56	8.35														
01-Aug-84	3		3.67			5.8	5.65	6.56	7.35														
01-Sep-84	3		3.67			4.8	4.65	5.06	6.85														
01-Oct-84	2		2.67			4.3	4.15	5.06	6.85														
01-Nov-84	6.5		5.17			6.8	8.65	8.06	8.85														
01-Dec-84	5.5		6.17			9.8	8.85	-1.94	8.85														
01-Feb-85	4		4.67			7.8	6.65	8.06	9.35														
01-Apr-85	3		-3.33			6.3	8.15	8.06	8.85														
01-May-85	4		-2.33			2.8	8.65	8.06	9.35														
01-Jun-85	3		3.17			3.8	8.15	8.06	10.35														
01-Jul-85	4.5		1.17			7.3	5.15	6.56	6.85														
23-Jul-85	2		2.17			4.8	5.15	6.56	8.35														
12-Aug-85						2.8	2.15	5.06	7.85														
03-Sep-85	4		1.17			2.8	2.65	4.56	5.35														
02-Oct-85	2.5		3.17			3.3	1.65	5.06	6.35														
07-Nov-85	5		5.17			5.8	6.15	6.56	8.35														
04-Dec-85			4.17			6.3	5.65	7.56	8.85														
01-Feb-86			3.67			6.3	6.65	9.06	8.85														
02-Apr-86			5.67			6.8	6.65	8.56															
05-May-86			4.67																				
06-May-86						8.8	9.65	10.06	9.35														
03-Jun-86			3.67			5.8	7.65	8.56	8.85														
07-Aug-86	3		3.17			6.8	6.65	6.56															
12-Mar-87					7.16																		
04-May-93														4.5	4.86	7.7							

Westport Water Level Elevations

	#36	#125	#127	#126	#37	#5	#6	#7	#4
		North		North					
	North #1	TW #1	North #2	TW #2	North #3	South #1	South #2	South #3	South #4
MP Elevatio	19.5	13.97	15.17	17.45	12.16	34.3	33.15	34.06	35.85
06-Jul-93									
14-Jul-93	2.9		3.37			7.4	6.55	6.06	9.05
16-Aug-93	2		2.27			5.5	5.15	4.76	5.25
06-Oct-93	0.5		2.37			5.2	4.05	2.56	4.75
20-Oct-93	2.29		2.49	3.1	2.64	5.08	4.29		
22-Oct-93	2.3		2.37			5.1	4.55	4.26	5.15
Maximum WL Elevations in Database									
	6.4	5.97	7.67	7.05	7.16	10.9	10.2	10.06	10.35

	#128		#129		#136	#137	#138	#8	#2	#1	#141	#135	#142	#134
	Lighthouse QC-1(WQ-2		Airport											
	elevations estimated		QC-2(WQ-1)					Old	Old	Old	Old South	Old South		elev. estl
	shallow (E)	deep (W)	shallow (S)	deep (N)	MW1	MW2	MW3	South 1	South 2	South 3	Obs. Well	Test Well	Peterson	Twin Har
MP Elevatio	26.26	27.65	10.66	10.87	10.12	9.58	13.72	35.1	33.1	34.8	15.69	30.68	8.67	10
06-Jul-93					2.34	3.26	5.34							
14-Jul-93	6.56	5.05	2.96	2.87										
16-Aug-93														
06-Oct-93														
20-Oct-93	4.76	4.1	3.07	3.03	1.6	2.86	3.29							
22-Oct-93														
Maximum WL Elevations in Database														
	6.56	5.05	3.07	3.03	4.5	4.86	7.7	10.2	9	8.9	7.5	10	7.8	7.08

APPENDIX 3

SELECTED WESTPORT WATER QUALITY

Selected Westport Water Quality

South Field

Date		Apr-49	25-May-60	25-Mar-69	05-Mar-79	25-Mar-82	07-Jul-83	06-Mar-84	05-Mar-85	09-Mar-88
Well		Well 3	Well 2	System	Well 4	System	Well 3	Well 2	System	Well 3
Arsenic	mg/l				0.027	< 0.01	0.007	0.002	<0.01	<0.01
Barium	mg/l				0.01	<0.25	0.02	0.02	<0.25	<0.25
Cadmium	mg/l				0.001	<0.002	0.001	0.001	<0.002	<0.002
Chrominum	mg/l				0.001	<0.01	0.003	0.001	<0.01	<0.01
Iron	mg/l	0.01	0.02	0.18	0.06	<0.05	0.025	0.01	<0.05	<0.1
Lead	mg/l				0.001	<0.01	0.001	0.001	<0.01	<0.01
Manganese	mg/l				0.062	<0.01	0.02	0.058	<0.01	0.045
Mercury	mg/l				0.0005	0.0005	0.0002	0.0005	<0.0005	<0.0005
Selenium	mg/l				0.003	<0.005	0.002	0.001	<0.003	<0.005
Silver	mg/l				0.001	<0.01	0.001	0.001	<0.01	<0.01
Sodium	mg/l		21	12.08		35	15	9	35	16
Hardness	mg/l	49.56	72	80	60	100	36	65	60	90
Conductivity	micromhos/cm		257	300	230	350	142	163	280	270
Turbidity	NTU			2	0.2	0.1	0.3	0.4	<0.1	0.2
Color	Color Units		5	9	16	<5	0.1	5	<5	<5
Fluoride	mg/l		0.1	0.06	0.1	<0.2	0.1	0.1	<0.2	<0.2
Nitrate	mg/l		0.7	0.02	0.3	1.3	1.1	0.2	<0.2	0.7
Chloride	mg/l	8	31	33.5		45	14	22	25	30

Shaded numbers indicate value greater than MCL.

Selected Westport Water Quality

North Field

Date		10-Jan-72	07-Dec-76	05-Mar-79	25-Mar-82	05-Mar-85	12-Mar-87	04-Apr-91
Well		Well 1	Well 2	Well 1	System	System	Well 3	Well 1
Arsenic	mg/l			0.022	< 0.01	<0.01	0.028	<0.01
Barium	mg/l			0.01	<0.25	<0.25	<0.25	<0.25
Cadmium	mg/l			0.001	<0.002	<0.002	<0.002	<0.002
Chrominum	mg/l			0.003	<0.01	<0.01	<0.01	<0.01
Iron	mg/l	0.04	0.04	0.19	<0.05	<0.05	0.09	<0.1
Lead	mg/l			0.024	<0.01	<0.01	<0.01	<0.0002
Manganese	mg/l	0.015	0.001	0.002	<0.01	<0.01	<0.01	<0.01
Mercury	mg/l			0.0005	0.0005	<0.0005	0.0011	<0.0005
Selenium	mg/l			0.001	<0.005	<0.003	<0.005	<0.005
Silver	mg/l			0.001	<0.01	<0.01	<0.01	<0.01
Sodium	mg/l	38			35	35	69	35
Hardness	mg/l	88	60	16	100	60	3	80
Conductivity	micromhos/cm	220		203	350	280	291	350
Turbidity	NTU	1.5	1	1.7	0.1	<0.1	0.1	0.1
Color	Color Units	5	5	20	<5	<5	5	15
Fluoride	mg/l	0.265	0.28	0.1	<0.2	<0.2	0.2	<0.2
Nitrate	mg/l	0.18	0.12	0.1	1.3	<0.2	<0.2	<0.2
Chloride	mg/l	19.5	35.3		45	25	17	25
Copper	mg/l						<0.1	<0.2
Zinc	mg/l						<0.1	<0.2

Shaded numbers indicate value greater than MCL.

APPENDIX 4

GRAYLAND PRECIPITATION DATA

Grayland Precipication Data

Month	Precip. (inches)	Remarks	Water Year Total (inches)
Oct-53	5.66		
Nov-53	11.92		
Dec-53	14.32		
Jan-54	16.97		
Feb-54	10.93		
Mar-54	4.39		
Apr-54	5.25		
May-54	1.53		
Jun-54	3.71		
Jul-54	1.91		
Aug-54	4.76		
Sep-54	2.62		83.97
Oct-54	4.50		
Nov-54	13.19		
Dec-54	10.36		
Jan-55	6.04		
Feb-55	5.61		
Mar-55	7.60		
Apr-55	8.36		
May-55	2.40		
Jun-55	2.23		
Jul-55	5.20		
Aug-55	0.18		
Sep-55	2.26		67.93
Oct-55	12.45		
Nov-55	11.72		
Dec-55	14.59		
Jan-56	13.84		
Feb-56	9.67		
Mar-56	12.35		
Apr-56	1.20		
May-56	1.52		
Jun-56	4.49		
Jul-56	1.48		
Aug-56	1.78		
Sep-56	4.09		89.18

e = official estimate; m = official data missing 10+ days, value estimated from Hoquim station data

Grayland Precipication Data

Month	Precip. (inches)	Remarks	Water Year Total (inches)
Oct-56	15.07		
Nov-56	3.72		
Dec-56	10.70	e	
Jan-57	6.66		
Feb-57	7.40		
Mar-57	9.57		
Apr-57	3.88		
May-57	2.66		
Jun-57	3.06		
Jul-57	1.57		
Aug-57	1.88		
Sep-57	1.09		67.26
Oct-57	5.67		
Nov-57	6.66		
Dec-57	12.78		
Jan-58	14.12		
Feb-58	9.63		
Mar-58	5.69		
Apr-58	7.32		
May-58	1.87		
Jun-58	2.04		
Jul-58	0.21		
Aug-58	1.58		
Sep-58	4.13		71.70
Oct-58	7.28		
Nov-58	12.69		
Dec-58	9.80		
Jan-59	12.19		
Feb-59	9.19		
Mar-59	10.33		
Apr-59	5.84		
May-59	3.32		
Jun-59	3.33		
Jul-59	1.52		
Aug-59	1.44		
Sep-59	7.84		84.77

e = official estimate; m = official data missing 10+ days, value estimated from Hoquim station data

Grayland Precipication Data

Month	Precip. (inches)	Remarks	Water Year Total (inches)
Oct-59	4.53		
Nov-59	11.80		
Dec-59	10.88		
Jan-60	10.48		
Feb-60	9.32		
Mar-60	7.10		
Apr-60	7.02		
May-60	7.80		
Jun-60	1.18		
Jul-60	0.12		
Aug-60	2.01		
Sep-60	2.44		74.68
Oct-60	6.83		
Nov-60	12.22		
Dec-60	7.60		
Jan-61	12.18		
Feb-61	19.30		
Mar-61	11.85		
Apr-61	5.57		
May-61	2.77		
Jun-61	1.24		
Jul-61	0.47		
Aug-61	1.01		
Sep-61	1.81		82.85
Oct-61	7.09		
Nov-61	10.04		
Dec-61	10.18		
Jan-62	7.42		
Feb-62	3.79		
Mar-62	5.98		
Apr-62	5.73		
May-62	3.64		
Jun-62	2.27		
Jul-62	0.59		
Aug-62	3.83		
Sep-62	3.41		63.97

e = official estimate; m = official data missing 10+ days, value estimated from Hoquim station data

Grayland Precipication Data

Month	Precip. (inches)	Remarks	Water Year Total (inches)
Oct-62	6.96		
Nov-62	14.21		
Dec-62	9.52		
Jan-63	4.58		
Feb-63	7.59		
Mar-63	5.17		
Apr-63	7.26		
May-63	2.63		
Jun-63	2.18		
Jul-63	1.89		
Aug-63	2.98		
Sep-63	2.51		67.48
Oct-63	9.72		
Nov-63	16.89		
Dec-63	7.64		
Jan-64	16.44		
Feb-64	4.82		
Mar-64	8.54		
Apr-64	3.70		
May-64	3.06		
Jun-64	2.86		
Jul-64	2.61		
Aug-64	3.25		
Sep-64	3.21		82.74
Oct-64	3.01		
Nov-64	12.29		
Dec-64	9.67		
Jan-65	15.08		
Feb-65	10.79		
Mar-65	2.03		
Apr-65	5.12		
May-65	2.61		
Jun-65	0.91		
Jul-65	0.53		
Aug-65	2.71		
Sep-65	0.62		65.37

e = official estimate; m = official data missing 10+ days, value estimated from Hoquim station data

Grayland Precipication Data

Month	Precip. (inches)	Remarks	Water Year Total (inches)
Oct-65	6.12		
Nov-65	11.50		
Dec-65	11.84		
Jan-66	11.17		
Feb-66	6.27		
Mar-66	10.05		
Apr-66	2.60		
May-66	2.04		
Jun-66	1.75		
Jul-66	0.71		
Aug-66	1.25		
Sep-66	2.35		67.65
Oct-66	7.78		
Nov-66	11.31		
Dec-66	16.18		
Jan-67	16.15		
Feb-67	6.88		
Mar-67	10.81		
Apr-67	4.40		
May-67	1.21		
Jun-67	1.14		
Jul-67	0.27		
Aug-67	0.30		
Sep-67	4.44		80.87
Oct-67	14.80		
Nov-67	6.42		
Dec-67	14.21		
Jan-68	11.88		
Feb-68	8.44		
Mar-68	11.65		
Apr-68	4.77		
May-68	3.65		
Jun-68	4.81		
Jul-68	1.15		
Aug-68	4.20		
Sep-68	5.16		91.14

e = official estimate; m = official data missing 10+ days, value estimated from Hoquim station data

Grayland Precipication Data

Month	Precip. (inches)	Remarks	Water Year Total (inches)
Oct-68	8.57		
Nov-68	9.89		
Dec-68	15.07		
Jan-69	9.76		
Feb-69	6.94		
Mar-69	4.14		
Apr-69	6.15		
May-69	3.98		
Jun-69	2.76		
Jul-69	0.73		
Aug-69	1.16		
Sep-69	7.13		76.28
Oct-69	4.48		
Nov-69	6.03		
Dec-69	11.17		
Jan-70	11.64		
Feb-70	4.38		
Mar-70	5.68		
Apr-70	7.98		
May-70	1.96		
Jun-70	0.97		
Jul-70	1.22		
Aug-70	0.47	e	
Sep-70	2.92		58.90
Oct-70	7.79	e	
Nov-70	7.80		
Dec-70	16.73		
Jan-71	14.90		
Feb-71	6.54		
Mar-71	13.15		
Apr-71	5.00		
May-71	2.53		
Jun-71	2.67		
Jul-71	1.55		
Aug-71	2.17		
Sep-71	7.55		88.38

e = official estimate; m = official data missing 10+ days, value estimated from Hoquim station data

Grayland Precipication Data

Month	Precip. (inches)	Remarks	Water Year Total (inches)
Oct-71	7.76		
Nov-71	10.04		
Dec-71	16.17		
Jan-72	10.79		
Feb-72	12.30		
Mar-72	13.83		
Apr-72	9.45		
May-72	1.01		
Jun-72	1.34		
Jul-72	4.50		
Aug-72	0.79		
Sep-72	6.48		94.46
Oct-72	1.97		
Nov-72	8.34	e	
Dec-72	15.34	e	
Jan-73	8.85	m	
Feb-73	4.02	e	
Mar-73	7.90		
Apr-73	2.20		
May-73	4.73		
Jun-73	4.64		
Jul-73	0.49		
Aug-73	0.51		
Sep-73	3.52		62.51
Oct-73	9.23		
Nov-73	13.52	m	
Dec-73	14.98	m	
Jan-74	14.67	m	
Feb-74	12.77		
Mar-74	11.02		
Apr-74	7.47		
May-74	5.54		
Jun-74	2.27	e	
Jul-74	3.02	m	
Aug-74	0.86		
Sep-74	0.59		95.93

e = official estimate; m = official data missing 10+ days, value estimated from Hoquim station data

Grayland Precipication Data

Month	Precip. (inches)	Remarks	Water Year Total (inches)
Oct-74	1.93		
Nov-74	8.62		
Dec-74	12.66	m	
Jan-75	12.83	e	
Feb-75	9.53		
Mar-75	6.74		
Apr-75	2.70		
May-75	3.67		
Jun-75	2.20		
Jul-75	0.23		
Aug-75	4.60		
Sep-75	0.22		65.93
Oct-75	15.69		
Nov-75	11.28	e	
Dec-75	13.47		
Jan-76	13.08	move,3S	
Feb-76	7.99		
Mar-76	7.45		
Apr-76	3.71		
May-76	3.91		
Jun-76	2.12		
Jul-76	2.70		
Aug-76	3.42		
Sep-76	2.10		86.92
Oct-76	3.85		
Nov-76	2.57	e	
Dec-76	3.53		
Jan-77	3.70	e	
Feb-77	5.36		
Mar-77	8.40		
Apr-77	2.61		
May-77	6.68		
Jun-77	1.51	e	
Jul-77	0.99		
Aug-77	3.16	e	
Sep-77	4.54		46.90

e = official estimate; m = official data missing 10+ days, value estimated from Hoquim station data

Grayland Precipication Data

Month	Precip. (inches)	Remarks	Water Year Total (inches)
Oct-77	6.02		
Nov-77	11.76		
Dec-77	12.29		
Jan-78	6.97	e	
Feb-78	4.17		
Mar-78	4.55		
Apr-78	2.45		
May-78	4.33		
Jun-78	2.12		
Jul-78	0.56		
Aug-78	2.38	e	
Sep-78	10.89		68.49
Oct-78	1.25		
Nov-78	5.64	e	
Dec-78	3.24		
Jan-79	2.97	e	
Feb-79	14.31	e	
Mar-79	6.45		
Apr-79	3.60	e	
May-79	3.63	e	
Jun-79	1.26		
Jul-79	1.21		
Aug-79	0.90	e	
Sep-79	2.74		47.20
Oct-79	8.32		
Nov-79	5.13	e	
Dec-79	13.65	e	
Jan-80	5.13	e	
Feb-80	9.94	e	
Mar-80	5.76		
Apr-80	4.08		
May-80	1.38		
Jun-80	1.58	e	
Jul-80	0.95		
Aug-80	0.93		
Sep-80	1.96		58.81

e = official estimate; m = official data missing 10+ days, value estimated from Hoquim station data

Grayland Precipication Data

Month	Precip. (inches)	Remarks	Water Year Total (inches)
Oct-80	3.17		
Nov-80	14.25	e	
Dec-80	10.15	e	
Jan-81	3.02		
Feb-81	7.18		
Mar-81	7.09		
Apr-81	8.11		
May-81	4.72		
Jun-81	4.99	m	
Jul-81	0.79		
Aug-81	1.22	m	
Sep-81	5.55	m	70.24
Oct-81	10.92		
Nov-81	11.15	m	
Dec-81	12.07	m	
Jan-82	14.18	m	
Feb-82	14.07	m	
Mar-82	7.25	m	
Apr-82	6.45	m	
May-82	0.66		
Jun-82	0.74		
Jul-82	1.30		
Aug-82	1.48		
Sep-82	3.68		83.95
Oct-82	1.71		
Nov-82	10.84		
Dec-82	13.59		
Jan-83	13.80		
Feb-83	13.49		
Mar-83	11.52		
Apr-83	4.41		
May-83	3.86		
Jun-83	3.96		
Jul-83	4.21	e	
Aug-83	1.44		
Sep-83	3.44		86.27

e = official estimate; m = official data missing 10+ days, value estimated from Hoquim station data

Grayland Precipication Data

Month	Precip. (inches)	Remarks	Water Year Total (inches)
Oct-83	3.21		
Nov-83	20.47		
Dec-83	8.90		
Jan-84	11.51		
Feb-84	11.22		
Mar-84	8.01		
Apr-84	7.10		
May-84	6.24		
Jun-84	3.58		
Jul-84	0.45		
Aug-84	0.88		
Sep-84	3.77		85.34
Oct-84	10.36		
Nov-84	15.69		
Dec-84	7.59		
Jan-85	0.88		
Feb-85	5.25		
Mar-85	7.75		
Apr-85	4.92		
May-85	1.15		
Jun-85	2.89		
Jul-85	0.36		
Aug-85	1.08		
Sep-85	3.67		61.59
Oct-85	12.12		
Nov-85	6.18		
Dec-85	2.99		
Jan-86	13.93		
Feb-86	9.02		
Mar-86	7.59		
Apr-86	4.80		
May-86	5.27		
Jun-86	2.52		
Jul-86	2.51		
Aug-86	0.28		
Sep-86	3.92		71.13

e = official estimate; m = official data missing 10+ days, value estimated from Hoquim station data

Grayland Precipication Data

Month	Precip. (inches)	Remarks	Water Year Total (inches)
Oct-86	4.93		
Nov-86	11.35		
Dec-86	9.19		
Jan-87	11.76		
Feb-87	6.34		
Mar-87	9.88		
Apr-87	4.72		
May-87	3.22	e	
Jun-87	0.71	e	
Jul-87	2.28		
Aug-87	0.46		
Sep-87	1.18		66.02
Oct-87	0.70		
Nov-87	8.40		
Dec-87	9.55		
Jan-88	8.83		
Feb-88	4.10		
Mar-88	9.10		
Apr-88	5.80		
May-88	5.96		
Jun-88	2.11		
Jul-88	1.66		
Aug-88	0.96		
Sep-88	2.76		59.93
Oct-88	5.02		
Nov-88	12.94		
Dec-88	8.40		
Jan-89	8.14		
Feb-89	6.19		
Mar-89	9.29		
Apr-89	3.64		
May-89	3.60		
Jun-89	2.23		
Jul-89	2.62		
Aug-89	1.24		
Sep-89	0.33		63.64

e = official estimate; m = official data missing 10+ days, value estimated from Hoquim station data

Grayland Precipication Data

Month	Precip. (inches)	Remarks	Water Year Total (inches)
Oct-89	8.60		
Nov-89	10.22		
Dec-89	6.60		
Jan-90	15.39		
Feb-90	13.86		
Mar-90	7.93		
Apr-90	5.29		
May-90	3.23		
Jun-90	3.67		
Jul-90	0.77		
Aug-90	2.09		
Sep-90	0.10		77.75
Oct-90	10.80		
Nov-90	17.61		
Dec-90	10.88		
Jan-91	7.38		
Feb-91	12.09		
Mar-91	5.71		
Apr-91	8.14		
May-91	4.07		
Jun-91	1.68		
Jul-91	0.82		
Aug-91	6.88		
Sep-91	0.14		86.20
Oct-91	2.64		
Nov-91	12.63		
Dec-91	7.09		
Jan-92	13.01		
Feb-92	5.94		
Mar-92	1.55		
Apr-92	9.16		
May-92	0.80		
Jun-92	1.00		
Jul-92	0.34		
Aug-92	1.48		
Sep-92	1.86		57.50

e = official estimate; m = official data missing 10+ days, value estimated from Hoquim station data

Grayland Precipication Data

Month	Precip. (inches)	Remarks	Water Year Total (inches)
Oct-92	5.32		
Nov-92	11.08		
Dec-92	8.93		
total avg	6.10		73.38

e = official estimate; m = official data missing 10+ days, value estimated from Hoquim station data

Westport Area Water Rights

Key: Ref # - Reference number of well data sheet
Name - Owner name
DOE # - Water Right number
Status: A = Active
C = Cancelled
R = Rejected
E = Error
V = Vested right

Location - Township/Range-section
QI - Instantaneous Discharge, gpm
QA - Annual discharge, acre-feet per year
Remarks - Surface water source, well name,

Ground Water Rights

REF #	NAME	DOE#	STATUS	LOCATION	QI	QA	REMARKS
	WILLIAMSON	G2-27824	A	15/11W-05M	10	16	
	MCDONALD	G2-04263	C	15/11W-05N	25	14	
	STRINDBERG	G2-27809	A	15/11W-05N	5	8	
	HARPER	G2-27815	A	15/11W-05R	200	322	
	CHAFIN	G2-08805	A	15/11W-07	35	6	SUMP
	HAMPTON	G2-06580	A	15/11W-07	300	6	SUMP
	HANNA	G2-03536	A	15/11W-07	498	13	INFIL TR
	HANNA	G2-00611	S	15/11W-07	498	13	INFIL TR
	HANNA	G2-20889	A	15/11W-07	60	15.2	SUMP
	HENDRICKSON	G2-06553	A	15/11W-07	200	7	INFIL TR
57	JOHNSTON	G2-05171	A	15/11W-07	12	19.2	
	PERTTULA	G2-00557	A	15/11W-07	5	0.5	
	JACOBSON	G2-08650	A	15/11W-07A	230	5.5	INFIL TR
	O'HAGAN	G2-00803	A	15/11W-07A	600	15	INFIL TR
	ROIKO	G2-03940	A	15/11W-07A	350	8	SUMP
	BOSS	G2-06251	A	15/11W-07H	353	9	SUMP
	JOHNSON	G2-03545	A	15/11W-07H	238	6	SUMP

Westport Area Water Rights

Key: Ref # - Reference number of well data sheet
Name - Owner name
DOE # - Water Right number
Status: A = Active
C = Cancelled
R = Rejected
E = Error
V = Vested right

Location - Township/Range-section
QI - Instantaneous Discharge, gpm
QA - Annual discharge, acre-feet per year
Remarks - Surface water source, well name,

Ground Water Rights

REF #	NAME	DOE#	STATUS	LOCATION	QI	QA	REMARKS
	QUINBY	G2-03564	A	15/11W-07H	300	6	INFIL TR
	JAATELA	G2-09179	A	15/11W-07J	360	12	INFIL TR
	YOCK	G2-03540	V	15/11W-07J	180	12	INFIL TR
	HILL	G2-08061	A	15/11W-08N	225	4.5	INFIL TR
	LILLEGAARD	G2-05477	A	15/11W-08N	200	5	INFIL TR
61	GRAYS HBR WAT	G2-20216	A	15/11W-17D	-	-	WELL #1
58	GRAYS HBR WAT	G2-24383	A	15/11W-17L	150	241	WELL #2
	OCEAN SPRAY	G2-23941	A	16/11W-02	200	230	
	CALDWELL	G2-23495	A	16/11W-10	7	3	
	NELSON	G2-23382	R	16/11W-10	15	24	
1-8	WESTPORT	G2-01002	A	16/11W-18M/N	700	1120	SOUTH WELLFIELD
10	OCOSTA SCH DIS	G2-27120	A	16/11W-19	200	12	
34	WA ST PARKS	G2-10201	A	16/12W-01	30	3	
127	WESTPORT	G2-24243	A	16/12W-12A	950	1120	NORTH WELL #2
36	WESTPORT	G2-00867	A	16/12W-12A	250	200	NORTH WELL #1
37	WESTPORT	G2-27060	A	16/12W-12B	500	403	NORTH WELL #3
39	MCPHAIL	G2-09837	A	16/12W-13	50	4.5	

Westport Area Water Rights

Key: Ref # - Reference number of well data sheet
Name - Owner name
DOE # - Water Right number
Status: A = Active
C = Cancelled
R = Rejected
E = Error
V = Vested right

Location - Township/Range-section
QI - Instantaneous Discharge, gpm
QA - Annual discharge, acre-feet per year
Remarks - Surface water source, well name,

Ground Water Rights

REF #	NAME	DOE#	STATUS	LOCATION	QI	QA	REMARKS
	WA ST PARKS	G2-00205	R	16/12W-24Jc	2	3.3	
	WA ST PARKS	G2-00206	R	16/12W-24Rb	2	3.3	
	ANDERSON	G2-20584	A	16/12W-25	10	1	
47	AYERS	G2-07553	A	16/12W-25	17	8	
45	GRAYLAND BCH	G2-21236	A	16/12W-25	15	2	
43	MOORE	G2-20616	A	16/12W-25	30	7.5	
44	ROWE	G2-07512	A	16/12W-25	20	1.8	
48	SLENES	G2-22173	A	16/12W-25	50	16.5	
	HARPER	G2-27820	A	16/11W-30M	50	80.5	

Westport Area Water Rights

Key: Ref # - Reference number of well data sheet
Name - Owner name
DOE # - Water Right number
Status: A = Active
C = Cancelled
R = Rejected
E = Error
V = Vested right

Location - Township/Range-section
QI - Instantaneous Discharge, gpm
QA - Annual discharge, acre-feet per year
Remarks - Surface water source, well name,

Surface Water Rights

REF #	NAME	DOE#	STATUS	LOCATION	QI	QA	REMARKS
	BLAKES PLAT	S2-04665	A	15/11W-05N	179.6	289	SWAMP CR
	BLAKES PLAT	S2-14983	A	15/11W-05N	134.7	216	SWAMP CR
	GRAYS HARBOR	S2-08666	C	15/11W-05N	134.7	216	SWAMP CR
	LAMMI	S2-27748	A	15/11W-05N	359	578	SWAMP CR
	MCDONALD	S2-15936	C	15/11W-05N	50	80.5	UNN STR
	CARSTENSEN	S2-05108	C	15/11W-05P	134.7	216	SWAMP CR
	WESTPORT	S2-08144	R	15/11W-06A	1796	2891	FLUME CR
	CONWAY	S2-00432	A	15/11W-06K	49	2	SWAMP CR
	CORDELL	S2-27791	A	15/11W-06N	449	723	SWAMP CR
	HAMPTON	S2-17396	R	15/11W-07	449	723	UNN STR
	HANNA	S2-20890	A	15/11W-07	36	2.2	BOG DITCH
	WILLIS	S2-18853	C	15/11W-07	22	14	UNN DRN DITCH
	FURFORD	S2-17012	A	15/11W-07A	180	4	UNN DRN DITCH
	CORDELL	S2-26259	A	15/11W-07B	2469	98	UNN DITCH
	BONER	S2-03004	A	15/11W-07D	225	362	BENN CR
	ERICKSON	S2-15197	A	15/11W-07H	296	6	UNN DITCH
	PERTTULA	S2-04667	A	15/11W-07H	27	43	UNN STR

Westport Area Water Rights

Key: Ref # - Reference number of well data sheet
Name - Owner name
DOE # - Water Right number
Status: A = Active
C = Cancelled
R = Rejected
E = Error
V = Vested right

Location - Township/Range-section
QI - Instantaneous Discharge, gpm
QA - Annual discharge, acre-feet per year
Remarks - Surface water source, well name,

Surface Water Rights

REF #	NAME	DOE#	STATUS	LOCATION	QI	QA	REMARKS
	CHRISTENSEN	S2-27150	A	15/11W-07J	148	6	SUMP
	HUORILA	S2-08445	R	15/11W-07J	570	917	UNN DRN DITCH
	JAATTELA	S2-08443	A	15/11W-07J	498	8017	UNN DRN DITCH
	LEMBERG	S2-08444	A	15/11W-07J	498	8017	DRN DITCH
	MULLINS	S2-00145	A	15/11W-07J	997	31	UNN DRN DITCH
	ARLENE	S2-27512	A	15/11W-07R	224	8.4	UNN DRN DITCH
	O'HAGAN	S2-25635	A	15/11W-08D	718	60	UNN STR
	PERTULLA	S2-22201	A	15/11W-08E	296	476	UNN STR
	HILL	S2-08480	R	15/11W-08N	498	801	UNN DRN DITCH
	SEA FARM PAC	S2-26964	A	16/11W-06	37310	60069	SEAWATER, NONCO
	HAGEN	S2-22874	A	16/11W-09	9.1	1	REDMAN CR
	GROSSMAN	S2-12756	E	16/11W-09R	455	732.5	UNN STR
	HARROW	S2-25312	A	16/11W-10G	9.1	1	UNN SPR
	GROSSMAN	S2-12756	E	16/11W-10N	455	732.5	UNN STR
	THOMAS	S2-14084	A	16/11W-11	4.5	7.2	UNN SPRS
	HOLLINGSWORT	S2-22634	A	16/11W-11B	9.1	1	UNN SPR
	WESTPORT	S2-07473	C	16/11W-32	674	1085	WILSON CR

Westport Area Water Rights

Key: Ref # - Reference number of well data sheet
Name - Owner name
DOE # - Water Right number
Status: A = Active
C = Cancelled
R = Rejected
E = Error
V = Vested right

Location - Township/Range-section
QI - Instantaneous Discharge, gpm
QA - Annual discharge, acre-feet per year
Remarks - Surface water source, well name,

Surface Water Rights

REF #	NAME	DOE#	STATUS	LOCATION	QI	QA	REMARKS
	WESTPORT	S2-06858	R	16/11W-32A	225	362.25	WILSON CR
	ROBERTS	S2-07702	C	16/11W-32M	444.5	715.6	UNN STR
	WESTPORT	S2-07465	C	16/11W-32M	898	1445.8	WEBB CR
	WESTPORT	S2-06858	R	16/11W-36A	225	362.25	WILSON CR

APPENDIX 5

WESTPORT AREA
WATER RIGHTS

APPENDIX 6

MONITOR WELL
STATE OF WASHINGTON
WATER WELL REPORTS

File Original and First Copy with Department of Ecology

Second Copy- Owner's Copy
Third Copy- Driller's Copy

WATER WELL REPORT
STATE OF WASHINGTON

Start Card No. 68132
Unique Well ID # ____
Water Right Permit No. ____

(1) OWNER: Name CITY OF WESTPORT Address PO BOX 505 WESTPORT, WA. 98595

(2) LOCATION OF WELL: County GRAYS HARBOR - NW ¼ SW ¼ Sec 1 M T 16 N., R 12W W.M.

(2a) STREET ADDRESS OF WELL (or nearest address) ____

(3) PROPOSED USE: ☐ Domestic ☐ Industrial ☐ Municipal ☐ Irrigation ☒ Test Well ☐ Other ☐ DeWater FOR WATER QUALITY

(4) TYPE OF WORK: Owners number of well (if more than one) MONITOR WELL 1
☐ Abandoned ☒ New well ☐ Deepened ☐ Reconditioned
Method: ☐ Dug ☐ Bored ☒ Cable ☐ Driven ☐ Rotary ☐ Jetted

(5) DIMENSIONS: Diameter of well 4 inches
Drilled 85 feet. Depth of completed well 85 ft.

(6) CONSTRUCTION DETAILS:
Casing installed: 4 " Diam. from +1.5 ft. to 85 ft.
☐ Welded ____ " Diam. from ____ ft. to ____ ft.
☐ Liner installed ____ " Diam. from ____ ft. to ____ ft.
☒ Threaded

Perforations: ☐ Yes ☒ No
Type of perforator used ____
Size of perforations ____ in. by ____ in.
____ perforations from ____ ft. to ____ ft.
____ perforations from ____ ft. to ____ ft.
____ perforations from ____ ft. to ____ ft.

Screens: ☒ Yes ☐ No
Manufacturer's Name AARDVARK
Type SCH 40 PVC Model No. ____
Diam. 4 Slot size 20 from 65 ft. to 85 ft.
Diam. ____ Slot size ____ from ____ ft. to ____ ft.
Diam. ____ Slot size ____ from ____ ft. to ____ ft.

Gravel packed: ☒ Yes ☐ No Size of gravel CSSI 8X12
Gravel placed from 59 ft. to 85 ft.

Surface Seal: ☒ Yes ☐ No To what depth? 59 ft.
Material used in seal ENVIROPLUG MED BENTONITE
Did any strata contain unusable water? ☐ Yes ☐ No
Type of water? ____ Depth of strata ____
Method of sealing strata off ____

(7) PUMP: Manufacturer's Name ____
Type: ____ H.P. ____

(8) WATER LEVELS: Land-surface elevation above mean sea level 20', EST. ft.
Static level 5.62 ft. below top of well Date 5/4/93
Artesian pressure ____ lbs. per square inch Date ____
Artesian water is controlled by ____ (cap, valve, etc.)

(9) WELL TESTS: Drawdown is amount water is lowered below static level
Was a pump test made? ☐ Yes ☐ No If yes, by whom? R&N
Yield: 62 gal./min. with 7.4 ft. drawdown after 2 hrs.
Ditch pump

Recovery data (time taken as zero when pump turned off)(water level measured from well top to water level)

Time	Water Level	Time	Water Level	Time	Water Level

Date of Test 4/27/93
Bailer test ____ gal./min. with ____ ft. drawdown after ____ hrs.
Airtest ____ gal./min. with stem set at ____ ft. for ____ hrs.
Artesian flow ____ g.p.m. Date ____
Temperature of water ____ Was a chemical analysis made? ☒ Yes ☐ No

(10) WELL LOG or ABANDONMENT PROCEDURE DESCRIPTION

Formation: Describe by color, character, size of material and structure, and show thickness of aquifers and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information.

MATERIAL	FROM	TO
SAND. VERY FINE TO FINE. BROWN.	0	24
SAND. FINE. BROWN. OCCASIONAL GRAVEL. SHELL	24	35
FRAGMENTS.		
SAND. FINE. GRAY-BROWN. GRAVELLY.	35	39
SHELL FRAGMENTS.		
SAND. FINE. GRAY. OCCASIONAL GRAVEL.	39	80
SAND. FINE. SILTY. GRAY.	80	85
Prepared by Robinson & Noble, Inc.		

Work started APRIL, 21, 1993. Completed APRIL, 21, 1993

WELL CONSTRUCTOR CERTIFICATION:

I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

NAME HOKKAIDO DRILLING & DEVELOPING (PERSON, FIRM, OR CORPORATION) (TYPE OR PRINT)

Address 10416 244TH ST E, GRAHAM 98338

(Signed) ____ (WELL DRILLER) License No. ____

Contractor's Registration No. ____ Date ____, 19 ____

File Original and First Copy with Department of Ecology

Second Copy- Owner's Copy
Third Copy- Driller's Copy

WATER WELL REPORT
STATE OF WASHINGTON

Start Card No. 68133
Unique Well ID # ____
Water Right Permit No. ____

(1) OWNER: Name CITY OF WESTPORT Address PO BOX 505 WESTPORT, WA. 98595

(2) LOCATION OF WELL: County GRAYS HARBOR - NW ¼ SW ¼ Sec 7 M T 16 N., R 11W W.M.
(2a) STREET ADDRESS OF WELL (or nearest address) ____

(3) PROPOSED USE: ☐ Domestic ☐ Industrial ☐ Municipal ☐ Irrigation ☒ Test Well ☐ Other ☐ DeWater FOR WATER QUALITY

(4) TYPE OF WORK: Owner's number of well (if more than one) MONITOR WELL 2
☐ Abandoned ☒ New well ☐ Deepened ☐ Reconditioned
Method: ☐ Dug ☐ Bored ☒ Cable ☐ Driven ☐ Rotary ☐ Jetted

(5) DIMENSIONS: Diameter of well 4 inches
Drilled 79 feet. Depth of completed well 79 ft.

(6) CONSTRUCTION DETAILS:
Casing installed: 4 " Diam. from +1.5 ft. to 79 ft.
☐ Welded ____ " Diam. from ____ ft. to ____ ft.
☐ Liner installed ____ " Diam. from ____ ft. to ____ ft.
☒ Threaded

Perforations: ☐ Yes ☒ No
Type of perforator used ____
Size of perforations ____ in. by ____ in.
____ perforations from ____ ft. to ____ ft.
____ perforations from ____ ft. to ____ ft.
____ perforations from ____ ft. to ____ ft.

Screens: ☒ Yes ☐ No
Manufacturer's Name AARDVARK
Type SCH 40 PVC Model No. ____
Diam. 4 Slot size 20 from 59 ft. to 79 ft.
Diam. ____ Slot size ____ from ____ ft. to ____ ft.
Diam. ____ Slot size ____ from ____ ft. to ____ ft.

Gravel packed: ☒ Yes ☐ No Size of gravel CSSI 8X12
Gravel placed from 57 ft. to 79 ft.

Surface Seal: ☒ Yes ☐ No To what depth? 57 ft.
Material used in seal ENVIROPLUG MED BENTONITE
Did any strata contain unusable water? ☐ Yes ☐ No
Type of water? ____ Depth of strata ____
Method of sealing strata off ____

(7) PUMP: Manufacturer's Name ____
Type: ____ H.P. ____

(8) WATER LEVELS: Land-surface elevation above mean sea level 15', EST. ft.
Static level 4.72 ft. below top of well Date 5/4/93
Artesian pressure ____ lbs. per square inch Date ____
Artesian water is controlled by ____ (cap, valve, etc.)

(9) WELL TESTS: Drawdown is amount water is lowered below static level
Was a pump test made? ☐ Yes ☐ No If yes, by whom? R&N
Yield: 75 gal./min. with 3.4 ft. drawdown after 2 hrs.
Ditch pump

Recovery data (time taken as zero when pump turned off)(water level measured from well top to water level)

Time	Water Level	Time	Water Level	Time	Water Level

Date of test 4/27/93
Bailer test ____ gal./min. with ____ ft. drawdown after ____ hrs.
Airtest ____ gal./min. with stem at ____ ft. for ____ hrs.
Artesian flow ____ g.p.m. Date ____
☒ Yes ☐ No

(10) WELL LOG or ABANDONMENT PROCEDURE DESCRIPTION

Formation: Describe by color, character, size of material and structure, and show thickness of aquifers and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information.

MATERIAL	FROM	TO
SAND, VERY FINE TO FINE, BROWN.	0	10
SAND, VERY FINE TO FINE, SILTY, DARK GRAY.	10	17
SAND, FINE, GRAY, OCCASIONAL GRANULES.	17	25
SAND, FINE TO MED, 15-30% PEA GRAVEL, GRAY-BRN.	25	29
PEA GRAVEL, WITH 15-20% FINE TO MED SAND, GRAY.	29	39
SAND, FINE TO MED, 10-20% PEA GRAVEL, GRAY.	39	46
SAND, FINE TO MED, AND PEA GRAVEL, BROWN-GRAY.	46	49
SAND, FINE TO MED, GRAY.	49	54
SAND, FINE TO MED, WITH ALTERNATING LAYERS OF	54	79
PEA GRAVEL, GRAY.		
Prepared by Robinson & Noble, Inc.		

Work started APRIL, 22, 1993. Completed APRIL, 22 1993

WELL CONSTRUCTOR CERTIFICATION:

I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

NAME HOKKAIDO DRILLING & DEVELOPING (PERSON, FIRM, OR CORPORATION) (TYPE OR PRINT)
Address 10416 244TH ST E, GRAHAM 98338
(Signed) ____ (WELL DRILLER) License No. ____
Contractor's Registration

File Original and First Copy with Department of Ecology

Second Copy- Owner's Copy
Third Copy- Driller's Copy

WATER WELL REPORT
STATE OF WASHINGTON

Start Card No. 68134
Unique Well ID #
Water Right Permit No.

(1) OWNER: Name CITY OF WESTPORT Address PO BOX 505 WESTPORT, WA. 98595

(2) LOCATION OF WELL: County GRAYS HARBOR - NW ¼ SW ¼ Sec 13L T 16 N., R 12W W.M.
(2a) STREET ADDRESS OF WELL (or nearest address)

(3) PROPOSED USE: ☐ Domestic ☐ Industrial ☐ Municipal ☐ Irrigation ☒ Test Well ☐ Other ☐ DeWater FOR WATER QUALITY

(4) TYPE OF WORK: Owner's number of well (if more than one) MONITOR WELL 3
☐ Abandoned ☒ New well ☐ Deepened ☐ Reconditioned
Method: ☐ Dug ☐ Bored ☒ Cable ☐ Driven ☐ Rotary ☐ Jetted

(5) DIMENSIONS: Diameter of well 4 inches
Drilled 71 feet. Depth of completed well 71 ft.

(6) CONSTRUCTION DETAILS:
Casing installed: 4 " Diam. from +1.5 ft. to 71 ft.
☐ Welded " Diam. from ft. to ft.
☐ Liner installed " Diam. from ft. to ft.
☒ Threaded

Perforations: ☐ Yes ☒ No
Type of perforator used
Size of perforations in. by in.
perforations from ft. to ft.
perforations from ft. to ft.
perforations from ft. to ft.

Screens: ☒ Yes ☐ No
Manufacturer's Name AARDVARK
Type SCH 40 PVC Model No.
Diam. 4 Slot size 20 from 51 ft. to 71 ft.
Diam. Slot size from ft. to ft.
Diam. Slot size from ft. to ft.

Gravel packed: ☒ Yes ☐ No Size of gravel CSSI 8X12
Gravel placed from 44.5 ft. to 71 ft.

Surface Seal: ☒ Yes ☐ No To what depth? 44.5 ft.
Material used in seal ENVIROPLUG MED BENTONITE
Did any strata contain unusable water? ☐ Yes ☐ No
Type of water? Depth of strata
Method of sealing strata off

(7) PUMP: Manufacturer's Name
Type: H.P.

(8) WATER LEVELS: Land-surface elevation above mean sea level 15' ,EST. ft.
Static level 6.02 ft. below top of well Date 5/4/93
Artesian pressure lbs. per square inch Date
Artesian water is controlled by (Cap, valve, etc.)

(9) WELL TESTS: Drawdown is amount water is lowered below static level
Was a pump test made? ☐ Yes ☐ No If yes, by whom? R&N
Yield: 61 gal./min. with 12.8 ft. drawdown after 2 hrs.
Ditch pump

Recovery data (time taken as zero when pump turned off)(water level measured from well top to water level)

Time	Water Level	Time	Water Level	Time	Water Level

Date of Test 4/27/93
Bailer test gal./min. with ft. drawdown after hrs.
Airtest gal./min. with stem set at ft. for hrs.
Artesian flow g.p.m. Date
Was a chemical analysis made? ☒ Yes ☐ No

(10) WELL LOG or ABANDONMENT PROCEDURE DESCRIPTION

Formation: Describe by color, character, size of material and structure, and show thickness of aquifers and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information.

MATERIAL	FROM	TO
SAND. VERY FINE TO FINE. BROWN.	0	20
SAND. FINE. BROWN-GRAY. OCCASIONAL GRANULE.	20	38
SAND. FINE TO MED. 10-30% PEA GRAVEL.GRAY-BROWN.	38	44
SHELLS.		
PEA GRAVEL. GRAY-BROWN.	44	46
SAND. FINE TO MED. SILTY. SOME GRANULES. GRAY.	46	71
Prepared by Robinson & Noble, Inc.		

Work started APRIL, 23 , 1993. Completed APRIL, 23 , 1993

WELL CONSTRUCTOR CERTIFICATION:

I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

NAME HOKKAIDO DRILLING & DEVELOPING (PERSON, FIRM, OR CORPORATION) (TYPE OR PRINT)
Address 10416 244TH ST E, GRAHAM 98338
(Signed) (WELL DRILLER) License No.
Contractor's Registration

File Original and First Copy with Department of Ecology

Second Copy- Owner's Copy
Third Copy- Driller's Copy

WATER WELL REPORT
STATE OF WASHINGTON

Start Card No. 63135
Unique Well ID # ____
Water Right Permit No. ____

(1) OWNER: Name CITY OF WESTPORT Address PO BOX 505 WESTPORT, WA. 98595

(2) LOCATION OF WELL: County GRAYS HARBOR - NW ¼ SW ¼ Sec 31 P. 16 N., R 11W W.M.
(2a) STREET ADDRESS OF WELL (or nearest address) ____

(3) PROPOSED USE: ☐ Domestic ☐ Industrial ☐ Municipal ☐ Irrigation ☒ Test Well ☐ Other ☐ DeWater FOR WATER QUALITY

(4) TYPE OF WORK: Owner's number of well (if more than one) MONITOR WELL 4
☐ Abandoned ☒ New well ☐ Deepened ☐ Reconditioned
Method: ☐ Dug ☐ Bored ☒ Cable ☐ Driven ☐ Rotary ☐ Jetted

(5) DIMENSIONS: Diameter of well 4 inches
Drilled 110 feet. Depth of completed well 108.5 ft.

(6) CONSTRUCTION DETAILS:
Casing installed: 4 " Diam. from +2.0 ft. to 108.5 ft.
☐ Welded ____ " Diam. from ____ ft. to ____ ft.
☐ Liner installed ____ " Diam. from ____ ft. to ____ ft.
☒ Threaded

Perforations: ☐ Yes ☒ No
Type of perforator used ____
Size of perforations ____ in. by ____ in.
____ perforations from ____ ft. to ____ ft.
____ perforations from ____ ft. to ____ ft.
____ perforations from ____ ft. to ____ ft.

Screens: ☒ Yes ☐ No
Manufacturer's Name AARDVARK
Type SCH 40 PVC Model No. ____
Diam. 4 Slot size 20 from 88.5 ft. to 108.5 ft.
Diam. ____ Slot size ____ from ____ ft. to ____ ft.
Diam. ____ Slot size ____ from ____ ft. to ____ ft.

Gravel packed: ☒ Yes ☐ No Size of gravel CSSI 8X12
Gravel placed from 84.5 ft. to 108.5 ft.

Surface Seal: ☒ Yes ☐ No To what depth? 84.5 ft.
Material used in seal ENVIROPLUG MED BENTONITE
Did any strata contain unusable water? ☐ Yes ☐ No
Type of water? ____ Depth of strata ____
Method of sealing strata off ____

(7) PUMP: Manufacturer's Name ____
Type: ____ H.P. ____

(8) WATER LEVELS: Land-surface elevation above mean sea level 15', EST. ft.
Static level 4.32 ft. below top of well Date 5/4/93
Artesian pressure ____ lbs. per square inch Date ____
Artesian water is controlled by ____ (Cap, valve, etc.)

(9) WELL TESTS: Drawdown is amount water is lowered below static level
Was a pump test made? ☐ Yes ☐ No If yes, by whom? R&N
Yield: 0.1 gal./min. with 28 ft. drawdown after .25 hrs.
Ditch pump

Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level)

Time	Water Level	Time	Water Level	Time	Water Level

Date of test 5/4/93
Bailer test ____ gal./min. with ____ ft. drawdown after ____ hrs.
Airtest ____ gal./min. with stem set at ____ ft. for ____ hrs.
Artesian flow ____ g.p.m. Date ____
Temperature of water ____ Was a chemical analysis made? ☐ Yes ☒ No

(10) WELL LOG or ABANDONMENT PROCEDURE DESCRIPTION

Formation: Describe by color, character, size of material and structure, and show thickness of aquifers and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information.

MATERIAL	FROM	TO
SAND, FINE, SILTY, PEATY, DARK BROWN	0	12
SAND, FINE, SILTY, WOODY, DARK GRAY-BROWN.	12	16
SAND, FINE, GRAY, OCCASIONAL GRANULE.	16	36
SAND, FINE, 5-10% GRANULES, SHELL FRAGMENTS.	36	49
GRAY, SILTY LAYERS BELOW 42'.		
SAND AND SILT, ORANGE-BROWN, OCCASIONAL	49	77.5
GRAVEL, WATER BEARING SEAMS. (SATSOP FM).		
SANDSTONE, FINE, SILTY, VERY COMPETENT, TAN-	77.5	80
BROWN.		
SILT, SAND AND GRAVEL, COMPACT, GRAY.	80	110
Prepared by Robinson & Noble, Inc.		

Work started APRIL, 26, 1993. Completed APRIL, 28, 199

WELL CONSTRUCTOR CERTIFICATION:

I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

NAME HOKKAIDO DRILLING & DEVELOPING (PERSON, FIRM, OR CORPORATION) (TYPE OR PRINT)

Address 10416 244TH ST E, GRAHAM 98338

(Signed) ____ (WELL DRILLER) License No. ____

Contractor's Registration

File Original and First Copy with Department of Ecology

Second Copy- Owner's Copy
Third Copy- Driller's Copy

WATER WELL REPORT
STATE OF WASHINGTON

Start Card No. 68136
Unique Well ID # ______
Water Right Permit No. ______

(1) OWNER: Name CITY OF WESTPORT Address PO BOX 505 WESTPORT, WA. 98595

(2) LOCATION OF WELL: County GRAYS HARBOR - NW ¼ SW ¼ Sec 7 K T 15 N., R 11W W.M.
(2a) STREET ADDRESS OF WELL (or nearest address) ______

(3) PROPOSED USE: ☐ Domestic ☐ Industrial ☐ Municipal ☐ Irrigation ☒ Test Well ☐ Other ☐ DeWater FOR WATER QUALITY

(4) TYPE OF WORK: Owners number of well (if more than one) MONITOR WELL 5
☐ Abandoned ☒ New well ☐ Deepened ☐ Reconditioned
Method: ☐ Dug ☐ Bored ☒ Cable ☐ Driven ☐ Rotary ☐ Jetted

(5) DIMENSIONS: Diameter of well 4 inches
Drilled 98 feet. Depth of completed well 83 ft.

(6) CONSTRUCTION DETAILS:
Casing installed: 4" Diam. from +1.5 ft. to 83 ft.
☐ Welded ______" Diam. from ______ ft. to ______ ft.
☐ Liner installed ______" Diam. from ______ ft. to ______ ft.
☐ Threaded

Perforations: ☐ Yes ☒ No
Type of perforator used ______
Size of perforations ______ in. by ______ in.
______ perforations from ______ ft. to ______ ft.
______ perforations from ______ ft. to ______ ft.
______ perforations from ______ ft. to ______ ft.

Screens: ☒ Yes ☐ No
Manufacturer's Name AARDVARK
Type SCH 40 PVC Model No. ______
Diam. 4 Slot size 20 from 63 ft. to 83 ft.
Diam. ______ Slot size ______ from ______ ft. to ______ ft.
Diam. ______ Slot size ______ from ______ ft. to ______ ft.

Gravel packed: ☒ Yes ☐ No Size of gravel CSSI 8X12
Gravel placed from 58.3 ft. to 83 ft.

Surface Seal: ☒ Yes ☐ No To what depth? 58.3 ft.
Material used in seal ENVIROPLUG MED BENTONITE
Did any strata contain unusable water? ☐ Yes ☐ No
Type of water? ______ Depth of strata ______
Method of sealing strata off ______

(7) PUMP: Manufacturer's Name ______
Type: ______ H.P. ______

(8) WATER LEVELS: Land-surface elevation above mean sea level 15', EST. ft.
Static level 3.0 ft. below top of well Date 5/4/93
Artesian pressure ______ lbs. per square inch Date ______
Artesian water is controlled by ______ (cap, valve, etc.)

(9) WELL TESTS: Drawdown is amount water is lowered below static level
Was a pump test made? ☐ Yes ☐ No If yes, by whom? R&N
Yield: 2 gal./min. with 20 ft. drawdown after 1 hrs.
Ditch pump

Recovery data (time taken as zero when pump turned off)(water level measured from well top to water level)

Time	Water Level	Time	Water Level	Time	Water Level

Date of test 5/4/93

Bailer test ______ gal./min. with ______ ft. drawdown after ______ hrs.
Airtest ______ gal./min. with stem set at ______ ft. for ______ hrs.
Artesian flow ______ g.p.m. Date ______
Was a chemical analysis made? ☒ Yes ☐ No

(10) WELL LOG or ABANDONMENT PROCEDURE DESCRIPTION

Formation: Describe by color, character, size of material and structure, and show thickness of aquifers and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information.

MATERIAL	FROM	TO
SAND, FINE TO MED. WITH WOOD AND PEAT.	0	2
DARK-BROWN.		
SAND, FINE, GRAY, OCCASIONAL GRANULE.	2	10
SAND, FINE TO MED. SLIGHTLY SILTY, GRAY.	10	25
SAND, FINE TO MED. GRAY, SHELL FRAGMENTS.	25	40
SAND, FINE TO MED. SILTY, AND PEA GRAVEL.	40	42
GRAY.		
SAND, FINE, 5-10% GRANULES, SHELL, FRAGMENTS.	42	48
GRAY, SILTY LAYERS.		
SAND AND SILT, ORANGE-BROWN, WATER BEARING	48	98
SEAMS. (SATSOP FM.).		
Prepared by Robinson & Noble, Inc.		

Work started APRIL, 29, 1993. Completed APRIL, 30, 1993

WELL CONSTRUCTOR CERTIFICATION:

I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

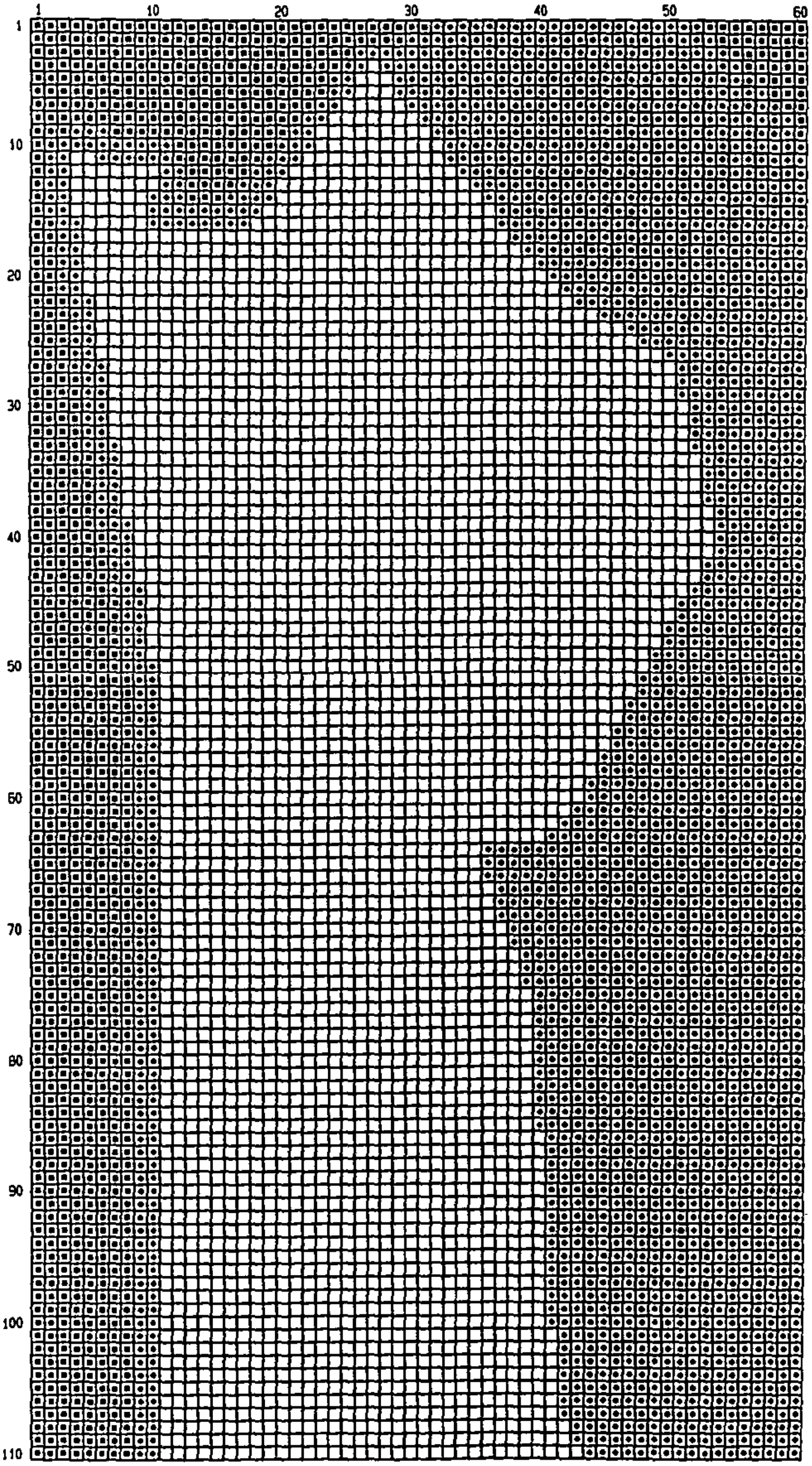
NAME HOKKAIDO DRILLING & DEVELOPING (PERSON, FIRM, OR CORPORATION) (TYPE OR PRINT)
Address 10416 244TH ST E, GRAHAM 98338
(Signed) ______ (WELL DRILLER) License No. ______
Contractor's Registration

APPENDIX 7

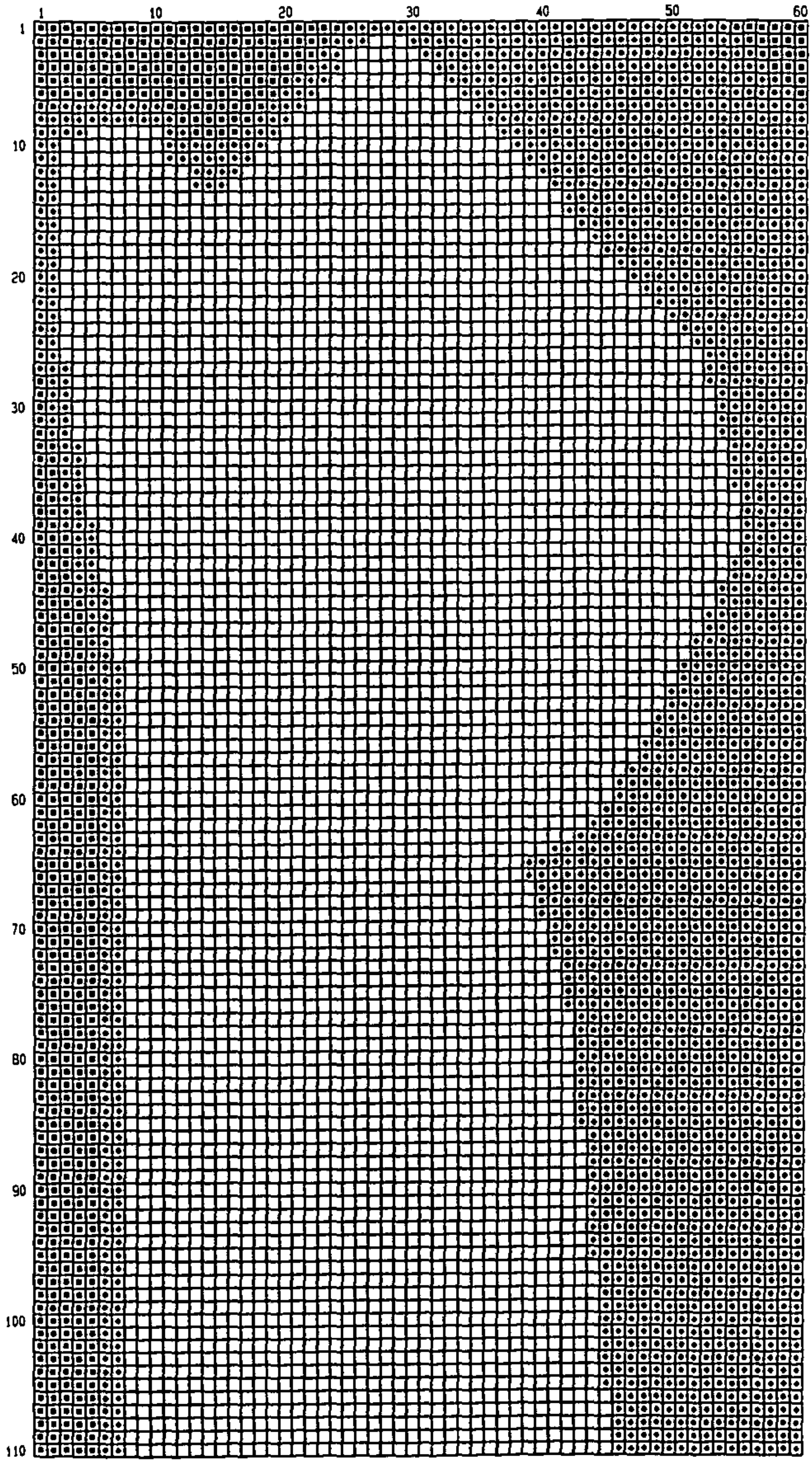
MODEL BOUNDARY CONDITIONS
AND
AQUIFER PARAMETERS

BOUNDARY CONDITIONS

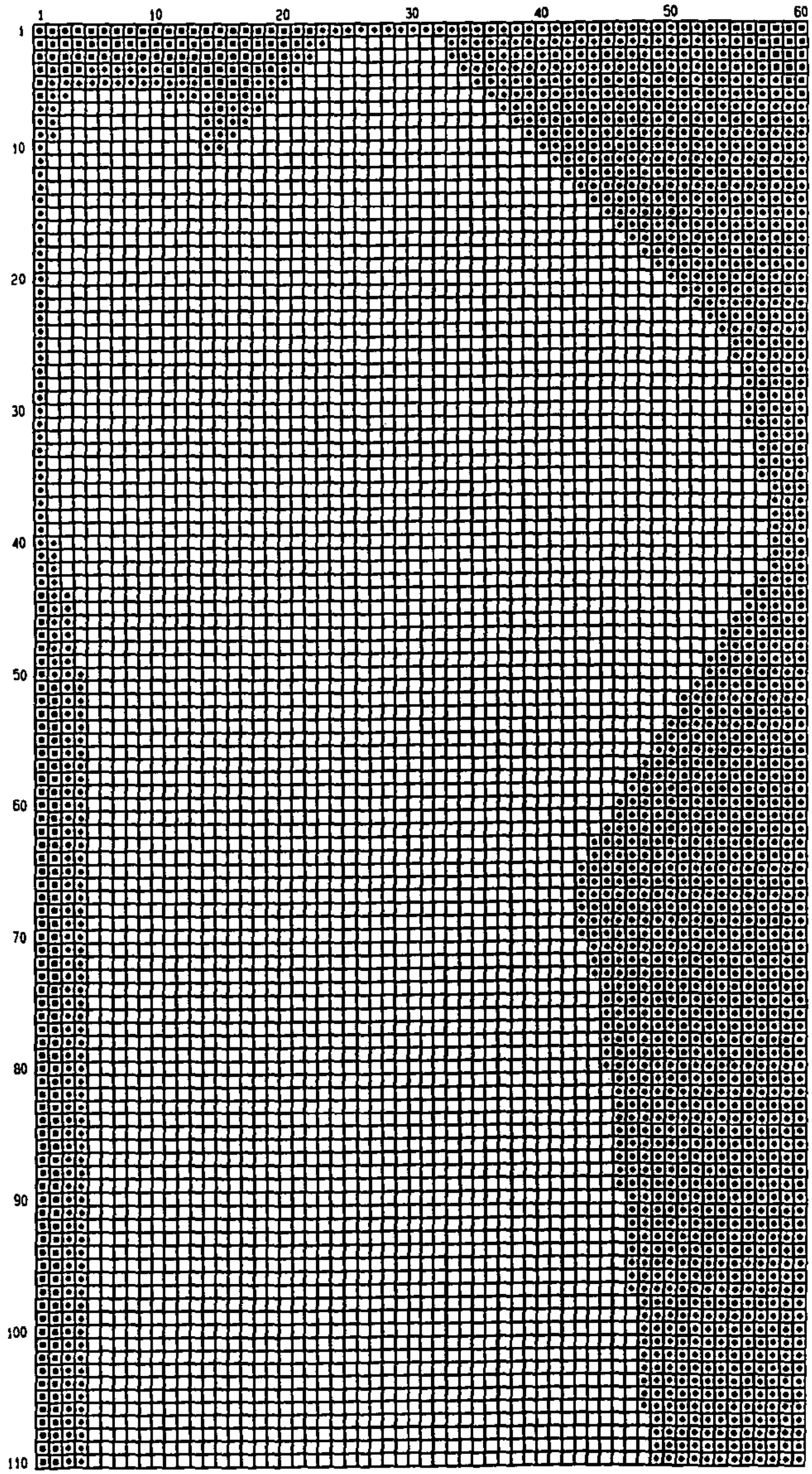
The following maps show the locations of active cells, no-flow (inactive) cells, and constant-head cells for each layer in the model. Constant-head cells are symbolized by solid diamonds. No-flow cells are symbolized by solid squares. No-flow cells are also shown in the aquifer parameter maps.



Layer 1, Constant Head and No-Flow Cells



Layer 2, Constant Head and No-Flow Cells

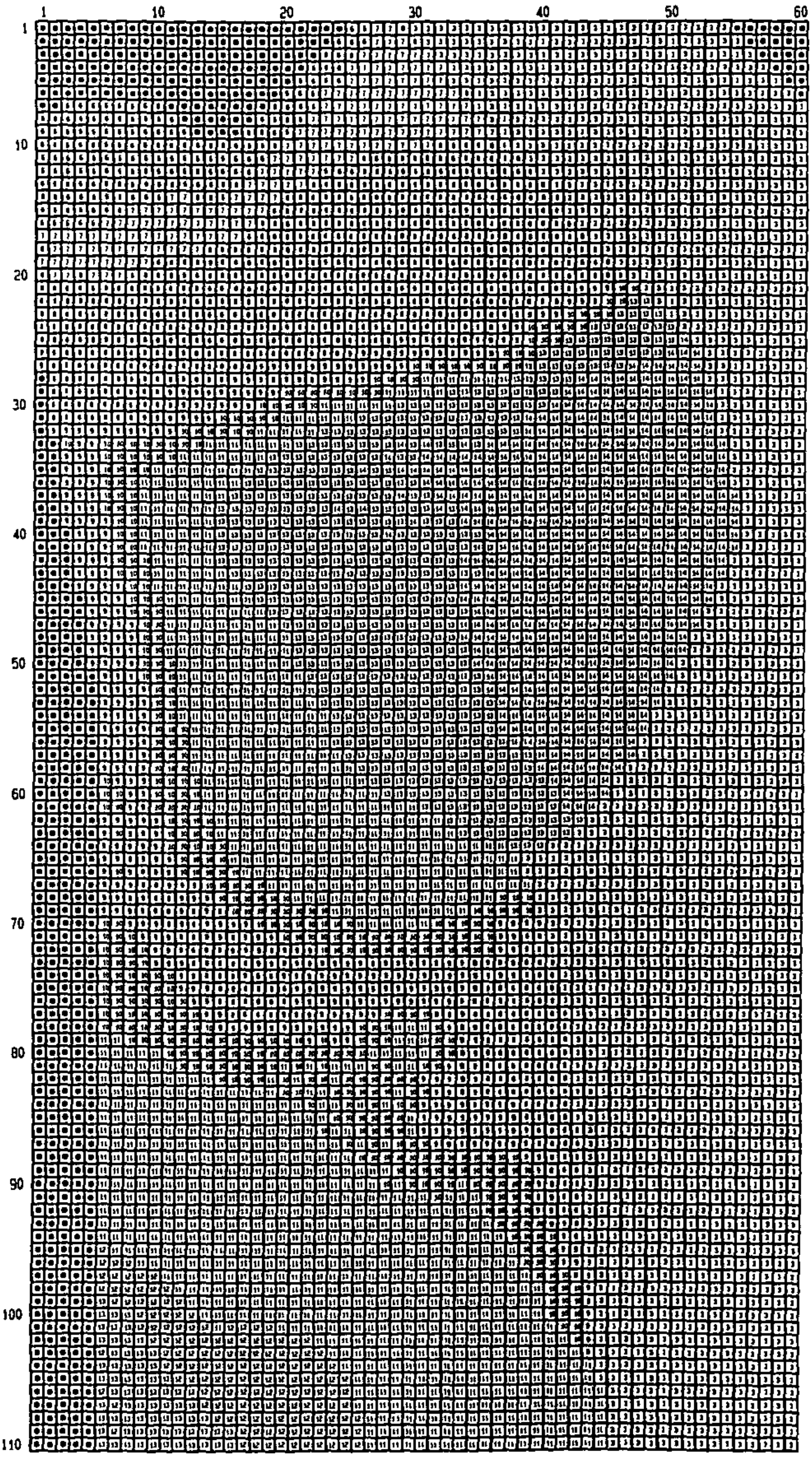


Layer 3, Constant Head and No-Flow Cells

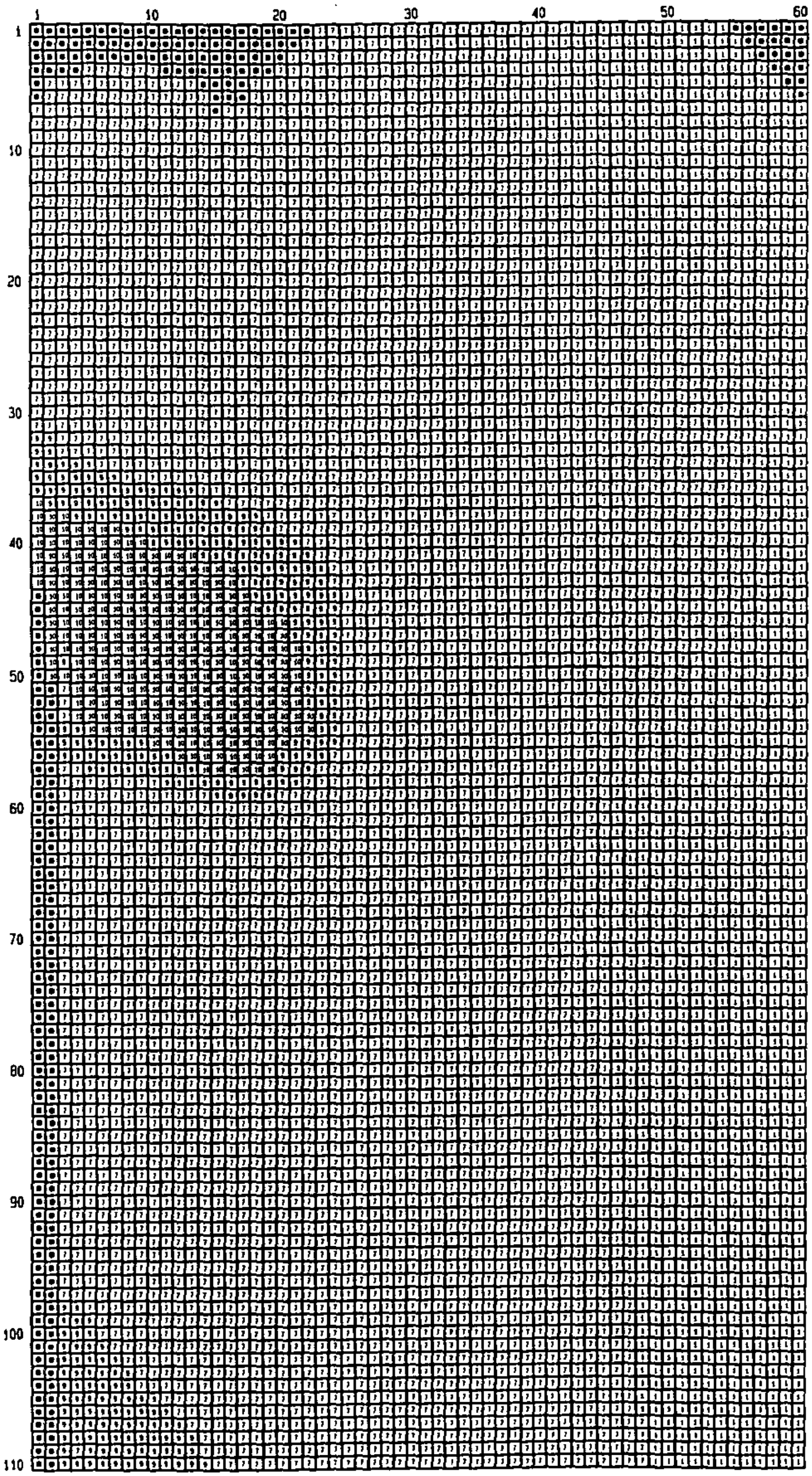
HYDRAULIC CONDUCTIVITY

The following maps show the assignment of hydraulic conductivity values for layers 2 and 3. Every cell in layer 1 has a value of 15 ft/day. The layer 2 and 3 maps give a ModelCad zonation number in each cell. These zonation numbers correspond to different hydraulic conductivity values as listed below:

Zone Number	Value (ft/day)
1	0.01
3	1
6	15
7	20
8	50
9	100
10	200
11	350
12	500
13	750
14	1000



Layer 2, Hydraulic Conductivity Zonation

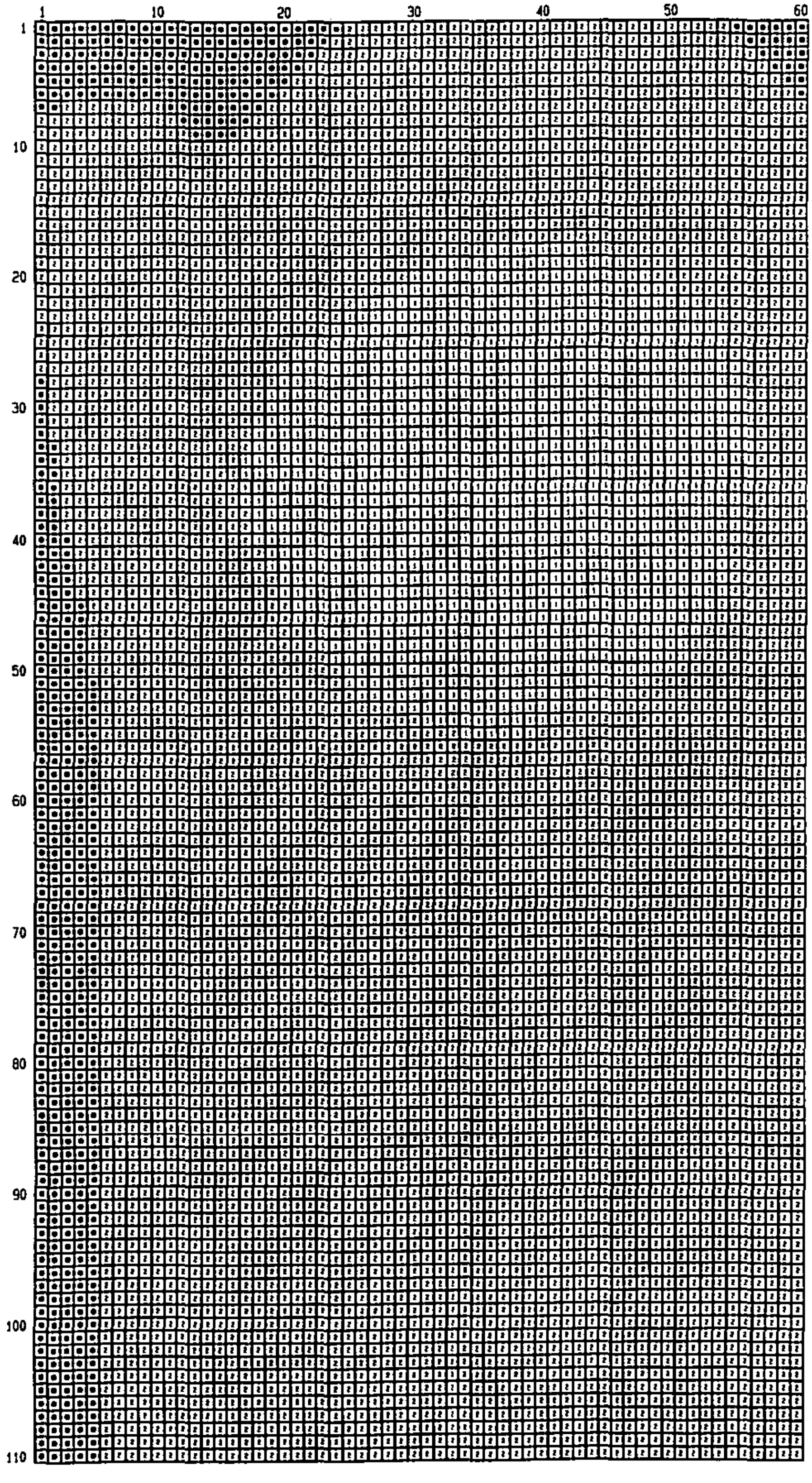


Layer 3, Hydraulic Conductivity Zonation

STORAGE

The following map show the assignment of storage values for layer 2. Every cell in layer 1 has a value of 0.2, every cell in layer 3 has a value of 0.1. The map gives a ModelCad zonation number in each cell. These zonation numbers correspond to different storage values as listed below:

Zone Number	Value
1	0.1
2	0.2

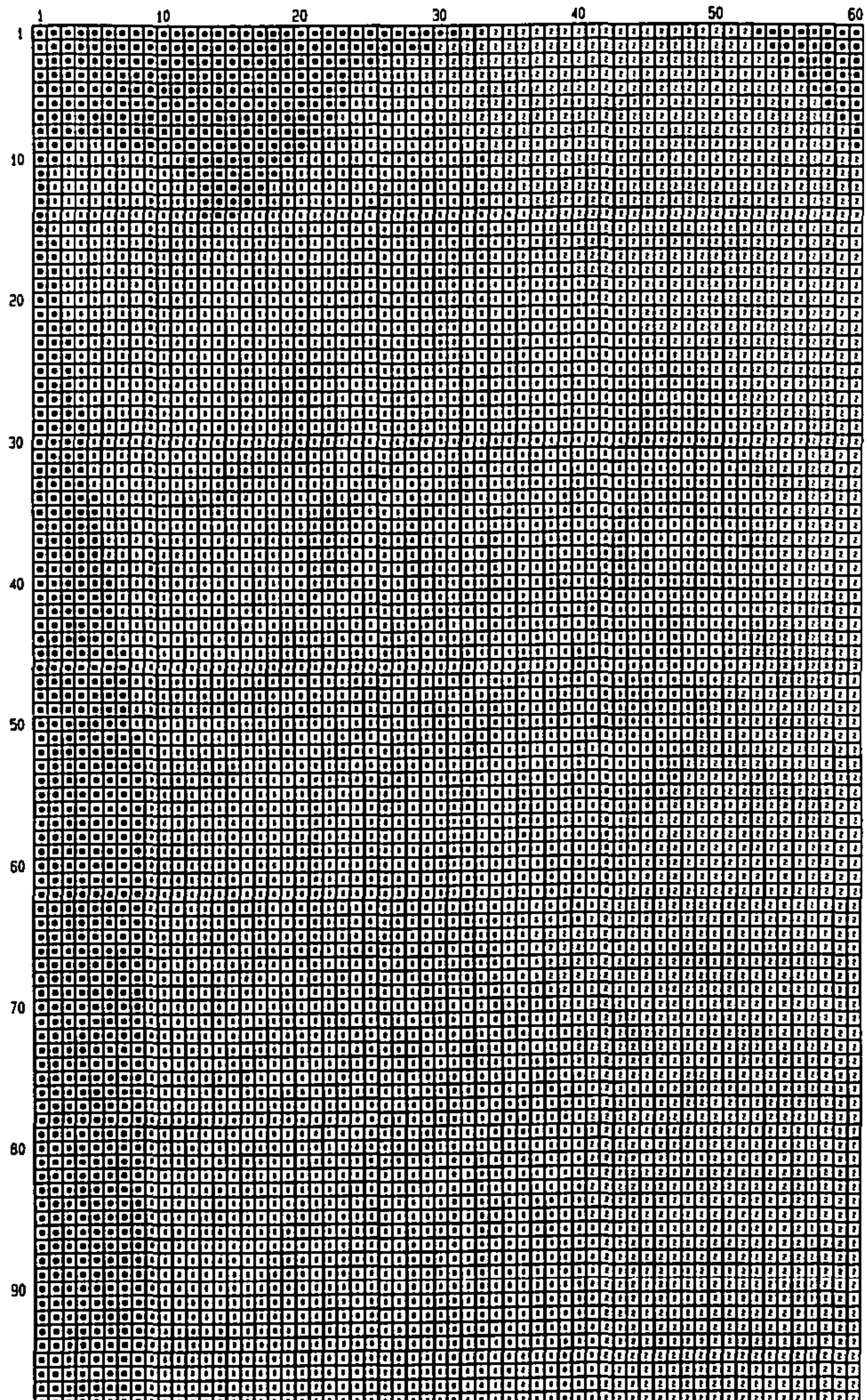


Layer 2, Storage Zonation

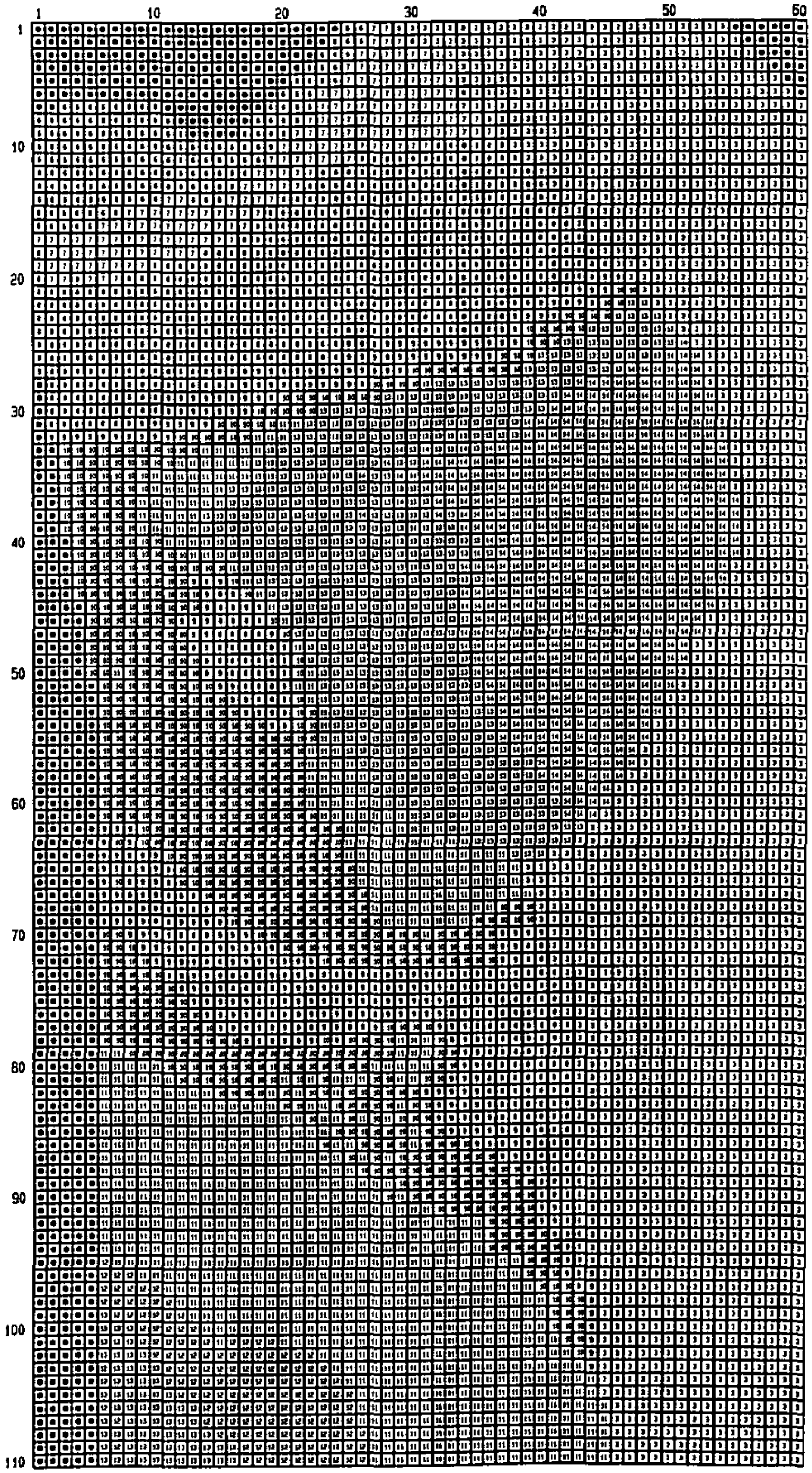
LEAKANCE

The following maps show the assignment of vertical hydraulic conductivity (leakance) values for layers 1 and 2. Leakance is not active in layer 3. The maps give a ModelCad zonation number in each cell. These zonation numbers correspond to different vertical hydraulic conductivity values as listed below:

Zone Number	Vertical Conductivity (ft/day)
2	0.01
3	0.1
6	1.5
7	2
8	5
9	10
10	20
11	35
12	50
13	75
14	100



Layer 1, Leakance Zonation

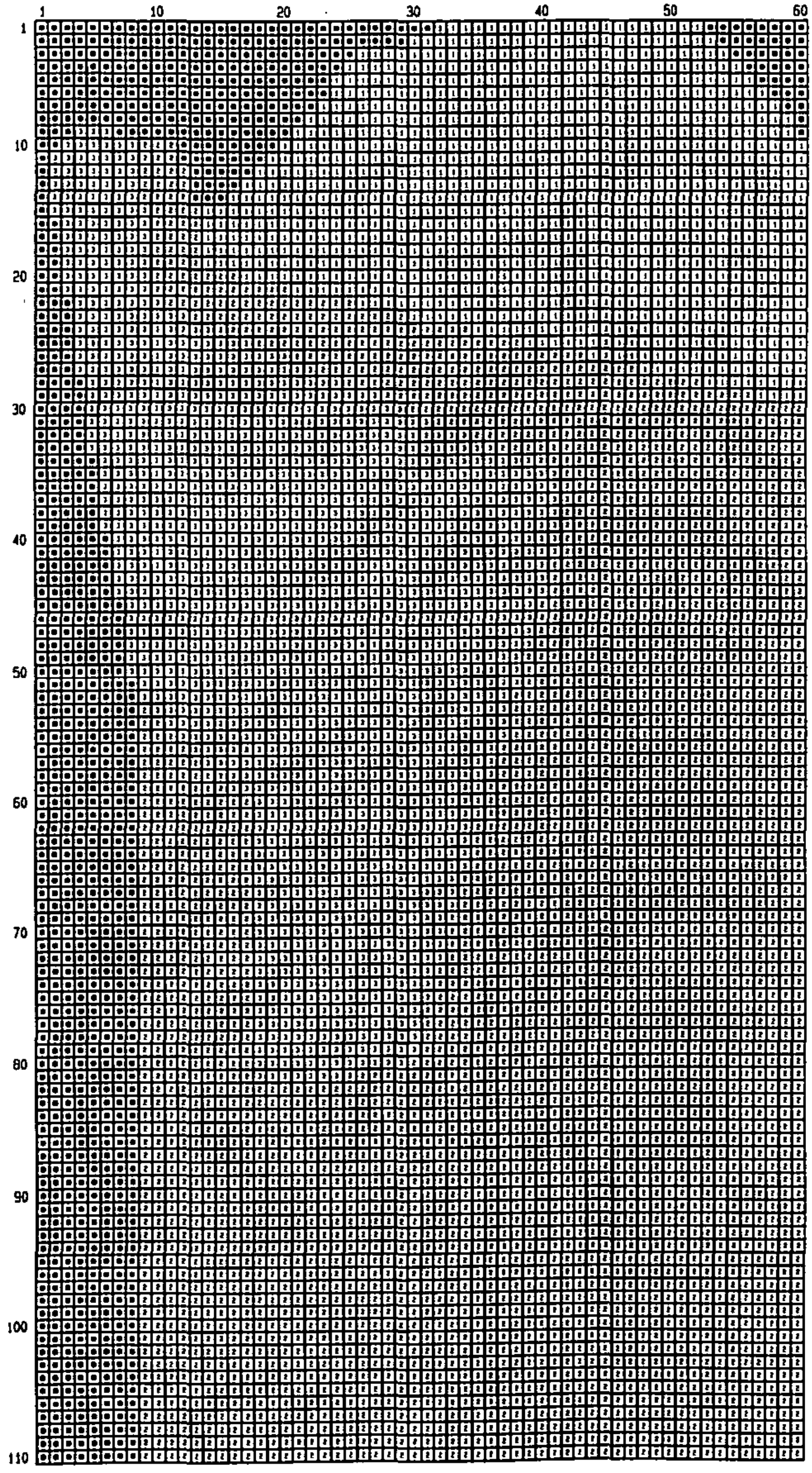


Layer 2, Leakance Zonation

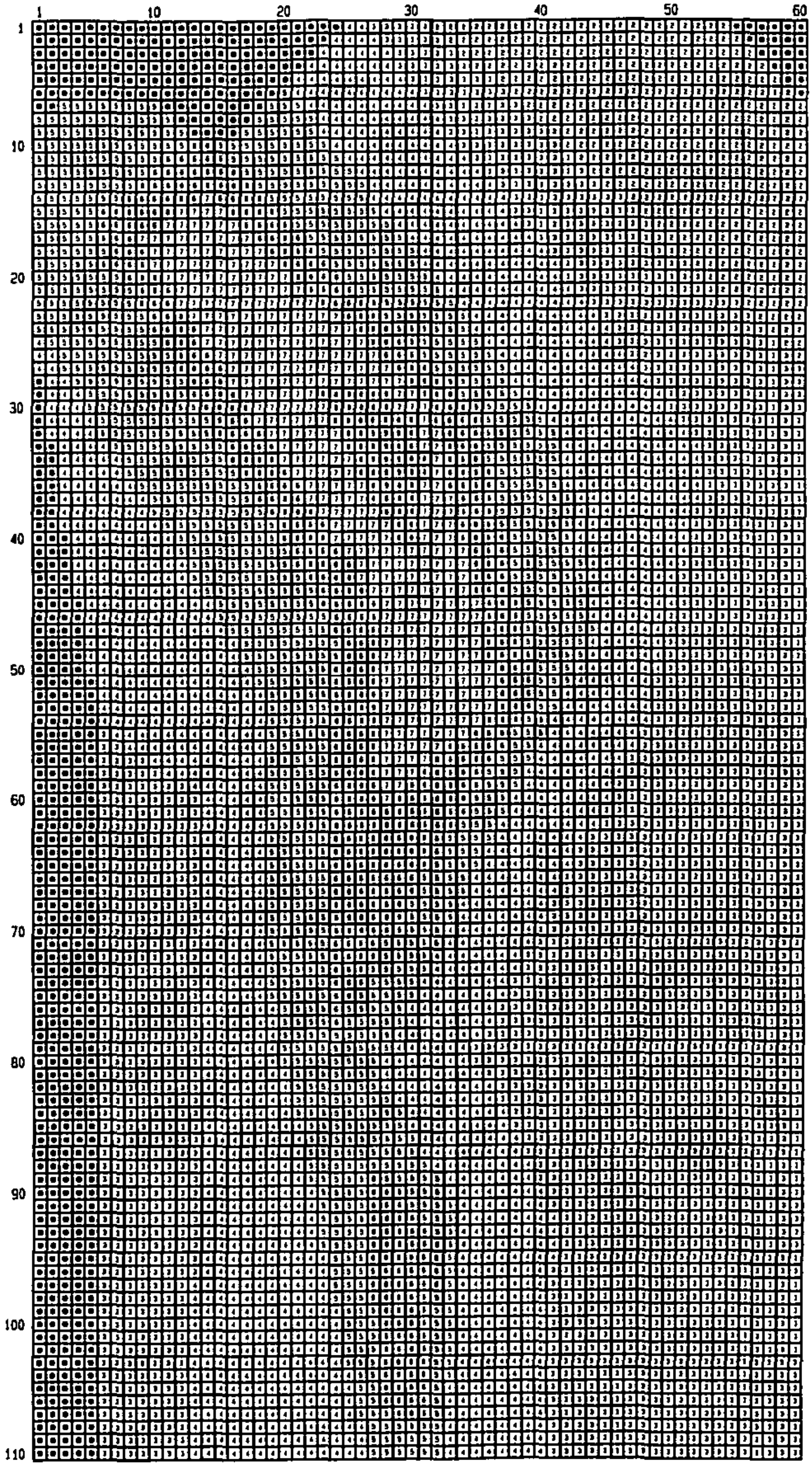
BOTTOM ELEVATION

The following maps show the assignment of bottom elevation values for layers 1, 2 and 3. The maps give a ModelCad zonation number in each cell. These zonation numbers correspond to different bottom elevation values as listed below:

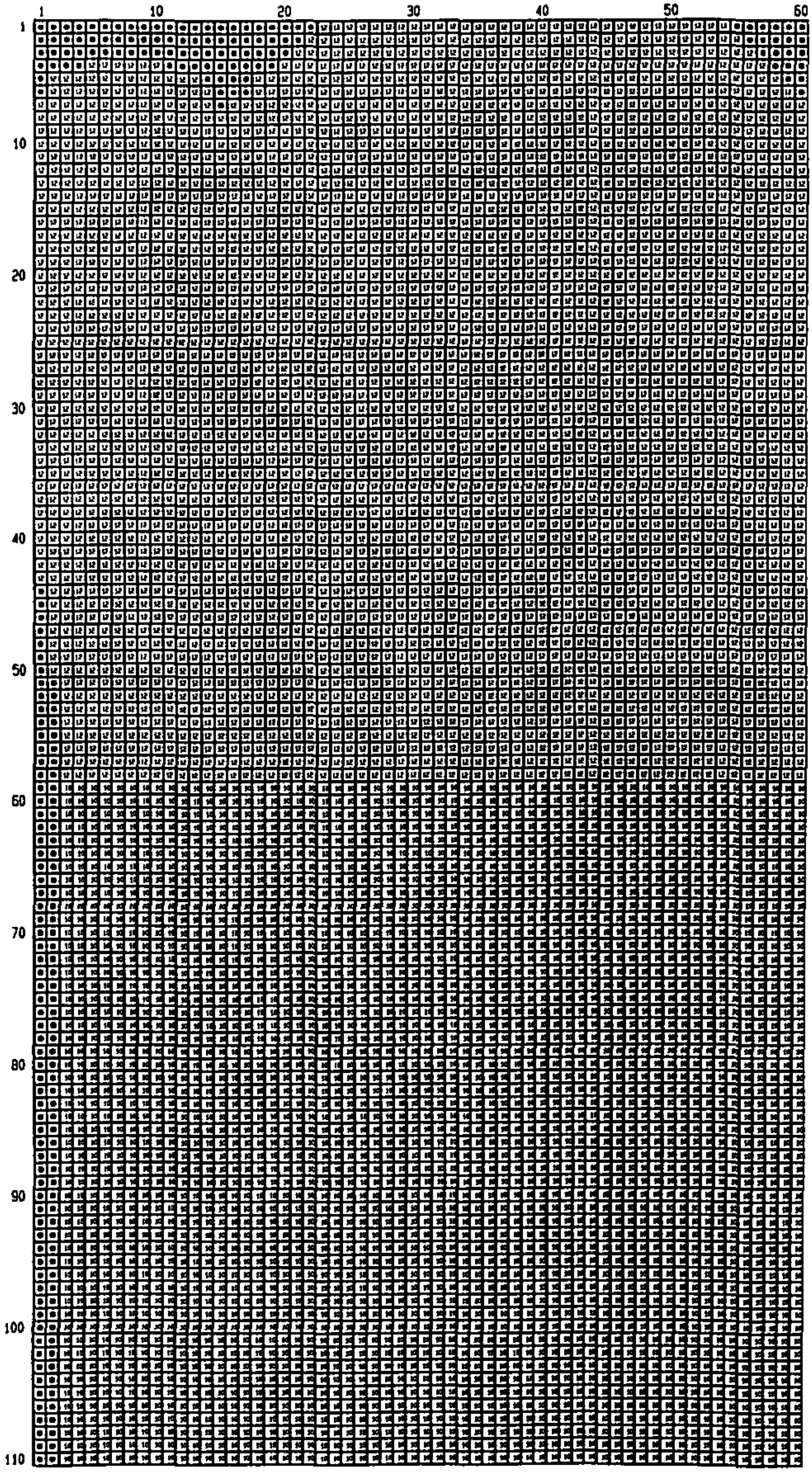
Zone Number	Bottom Elevation (ft)
1	-10
2	-20
3	-30
4	-40
5	-50
6	-60
7	-70
8	-80
9	-90
10	-100
12	-120



Layer 1, Bottom Elevation Zonation



Layer 2, Bottom Elevation Zonation



Layer 3, Bottom Elevation Zonation

APPENDIX 8

VERIFICATION RUN DATA

Production Values Used in Verification Runs

All production data are in cubic ft/ per day

North 1	North 2	South 1	South 2	Date
8376	14401	17523	17523	Jan-83
5964	17505	13494	13494	Feb-83
12331	10847	18459	18459	Mar-83
11400	9987	19739	19739	Apr-83
27861	28004	9208	9208	May-83
22524	36848	10186	10186	Jun-83
26072	34758	13040	13040	Jul-83
25507	34007	17681	17681	Aug-83
17287	23054	12213	12213	Sep-83
17105	22802	11298	11298	Oct-83
4871	6493	19723	19723	Nov-83
17929	23906	20918	20918	Dec-83
16096	10075	18459	18459	Jan-84
15186	7395	15306	15306	Feb-84
21301	15237	20849	20849	Mar-84
10357	12719	22350	22350	Apr-84
8984	1579	22654	22654	May-84
12211	14867	23812	23812	Jun-84
8910	24877	25638	25638	Jul-84
14513	30402	24700	24700	Aug-84
19311	1257	23676	23676	Sep-84
4654	2001	24055	24055	Oct-84
5887	7764	18609	18609	Nov-84
5184	5676	20240	20240	Dec-84
4248	4589	20734	20734	Jan-85
6389	4350	18537	18537	Feb-85
5952	9475	23130	23130	Mar-85
6542	6132	20534	20534	Apr-85
11347	7940	23456	23456	May-85
19788	16369	18460	18460	Jun-85
17424	45488	24292	24292	Jul-85
18981	40433	25619	25619	Aug-85
17047	12586	21207	21207	Sep-85
9290	10894	21625	21625	Oct-85
6123	11422	19741	19741	Nov-85
0	14733	25358	25358	Dec-85
0	37406	5848	5848	Jan-86
0	16455	19535	19535	Feb-86
0	7466	25442	25442	Mar-86
0	26727	20102	20102	Apr-86
0	42327	15667	15667	May-86
0	34067	26544	26544	Jun-86

Recharge Values Used for Verification Runs

Effect. Recharge (inches)	Recharge for stress period (ft/d)	Multiplier for next val. of recharge	Month
12.65	0.03401		Jan-83
12.34	0.03673	1.08001	Feb-83
9.77	0.02626	0.77233	Mar-83
2.21	0.00614	0.18053	Apr-83
1.06	0.00285	0.08379	May-83
0.96	0.00267	0.07842	Jun-83
0.96	0.00258	0.07589	Jul-83
0	0.00001	0.00029	Aug-83
1.24	0.00344	0.10129	Sep-83
1.46	0.00392	0.11542	Oct-83
19.17	0.05325	1.56593	Nov-83
7.75	0.02083	0.61265	Dec-83
10.36	0.02785	0.81897	Jan-84
10.07	0.02894	0.85095	Feb-84
6.26	0.01683	0.49486	Mar-84
4.9	0.01361	0.40026	Apr-84
3.44	0.00925	0.27194	May-84
0.58	0.00161	0.04738	Jun-84
0	0.00001	0.00029	Jul-84
0	0.00001	0.00029	Aug-84
1.57	0.00436	0.12825	Sep-84
8.61	0.02315	0.68063	Oct-84
14.39	0.03997	1.17547	Nov-84
6:44	0.01731	0.50909	Dec-84
0	0.00001	0.00029	Jan-85
4.1	0.01220	0.35884	Feb-85
6	0.01613	0.47431	Mar-85
2.72	0.00756	0.22219	Apr-85
0	0.00001	0.00029	May-85
0	0.00001	0.00029	Jun-85
0	0.00001	0.00029	Jul-85
0	0.00001	0.00029	Aug-85
1.47	0.00408	0.12008	Sep-85
10.37	0.02788	0.81976	Oct-85
4.88	0.01356	0.39863	Nov-85

Recharge Values Used for Verification Runs

Effect. Recharge (inches)	Recharge for stress period (ft/d)	Multiplier for next val. of recharge	Month
1.84	0.00495	0.14545	Dec-85
12.78	0.03435	1.01028	Jan-86
7.87	0.02342	0.68879	Feb-86
5.84	0.01570	0.46166	Mar-86
2.6	0.00722	0.21238	Apr-86
2.47	0.00664	0.19526	May-86
0	0.00001	0.00029	Jun-86

APPENDIX 9

SENSITIVITY STUDY RESULTS

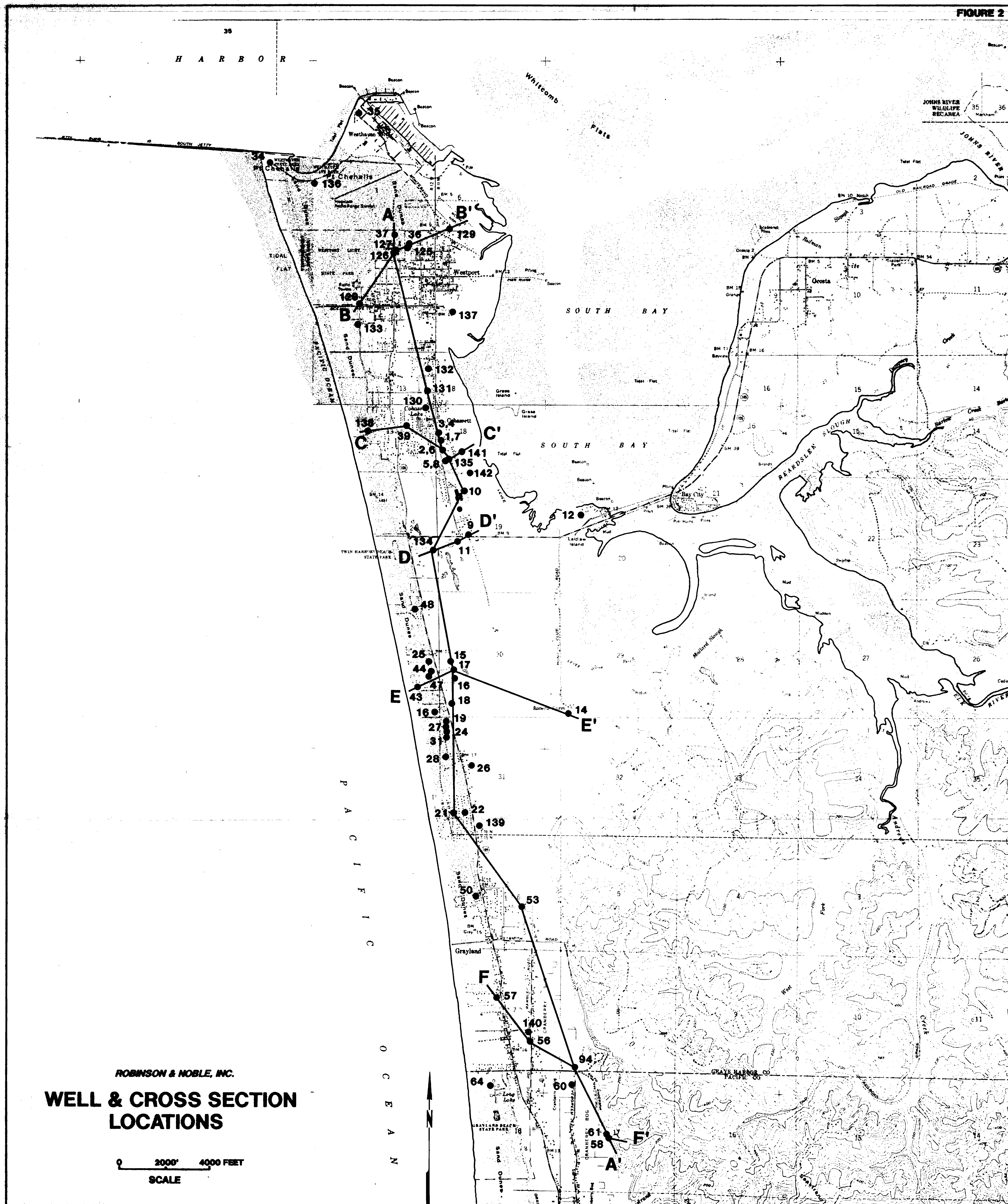
SENSITIVITY STUDY RESULTS

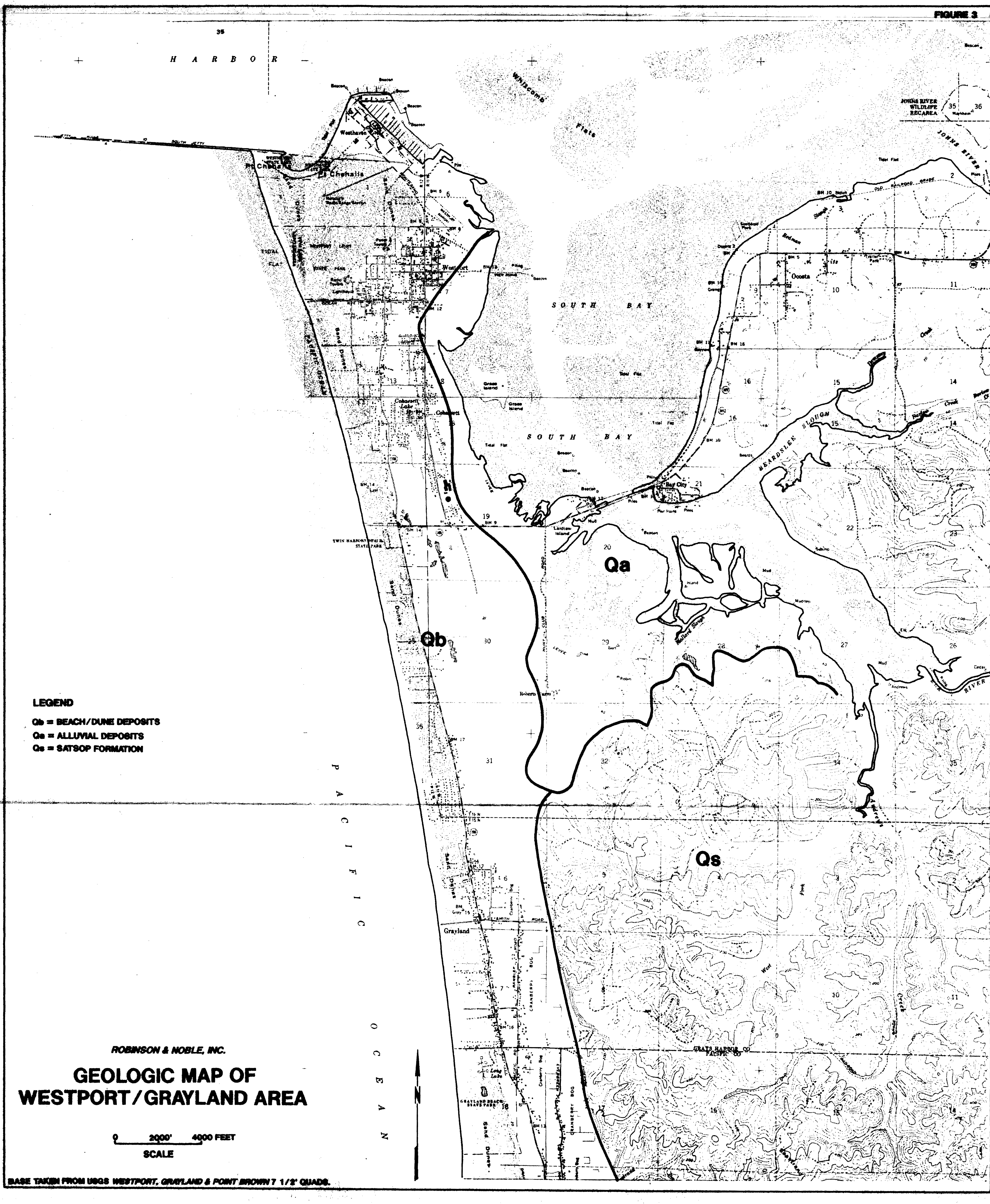
The calibrated model was subjected to global changes in hydraulic conductivity and vertical hydraulic conductivity (leakance) to assess the model's sensitivity to these variables. Listed below are the mean absolute errors that resulted from the global changes. The 0 percent change represents the calibrated model.

Changes in Hydraulic Conductivity		
Percent Change		Mean Absolute Error
-75		14.5
-50		5.19
0		0.34
+50		1.97
+75		2.49

Changes in Leakance		
Percent Change		Mean Absolute Error
-75		1.04
-50		0.51
0		0.34
+50		0.38
+75		0.42

FIGURE 2

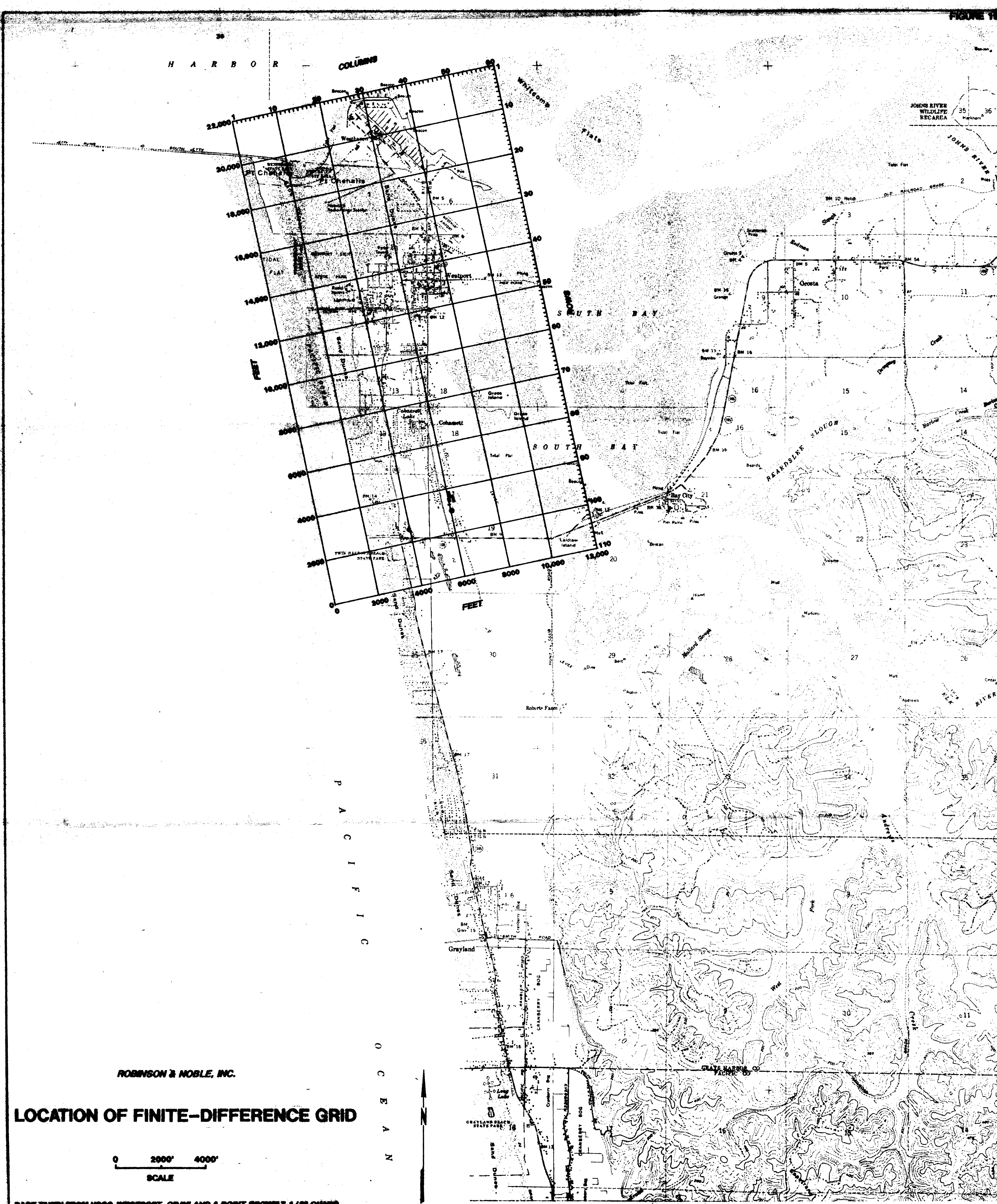

ROBINSON & NOBLE, INC.
WELL & CROSS SECTION LOCATIONS
0 2000' 4000 FEET
SCALE
BASE TAKEN FROM USGS WESTPORT, GRAYLAND & POINT BROWN 7 1/2' QUADS.
HARBOR
PACIFIC OCEAN
SOUTH BAY
Whitcomb Flats
Westport
Westhaven
Cohassett
Grayland
Ocosta
Bay City
Laidlaw Island
TWIN HARBORS BEACH STATE PARK
GRAYLAND BEACH STATE PARK
JOHNS RIVER WILDLIFE RECAREA
JOHNS RIVER
BEARDSLEE SLOUGH
ELK RIVER
Sand Dunes
Long Lake
GRAYS HARBOR CO
PACIFIC CO
A
A'
B
B'
C
C'
D
D'
E
E'
F
F'
N



ROBINSON & NOBLE, INC.

GEOLOGIC MAP OF WESTPORT/GRAYLAND AREA

BASE TAKEN FROM USGS *WESTPORT, GRAYLAND & POINT BROWN* 7 1/2' QUADS.



ROBINSON & NOBLE, INC.

LOCATION OF FINITE–DIFFERENCE GRID

0 2000' 4000'
SCALE

BASE TAKEN FROM USGS WESTPORT, GRAYLAND & POINT BROWN 7 1/2" QUADS.

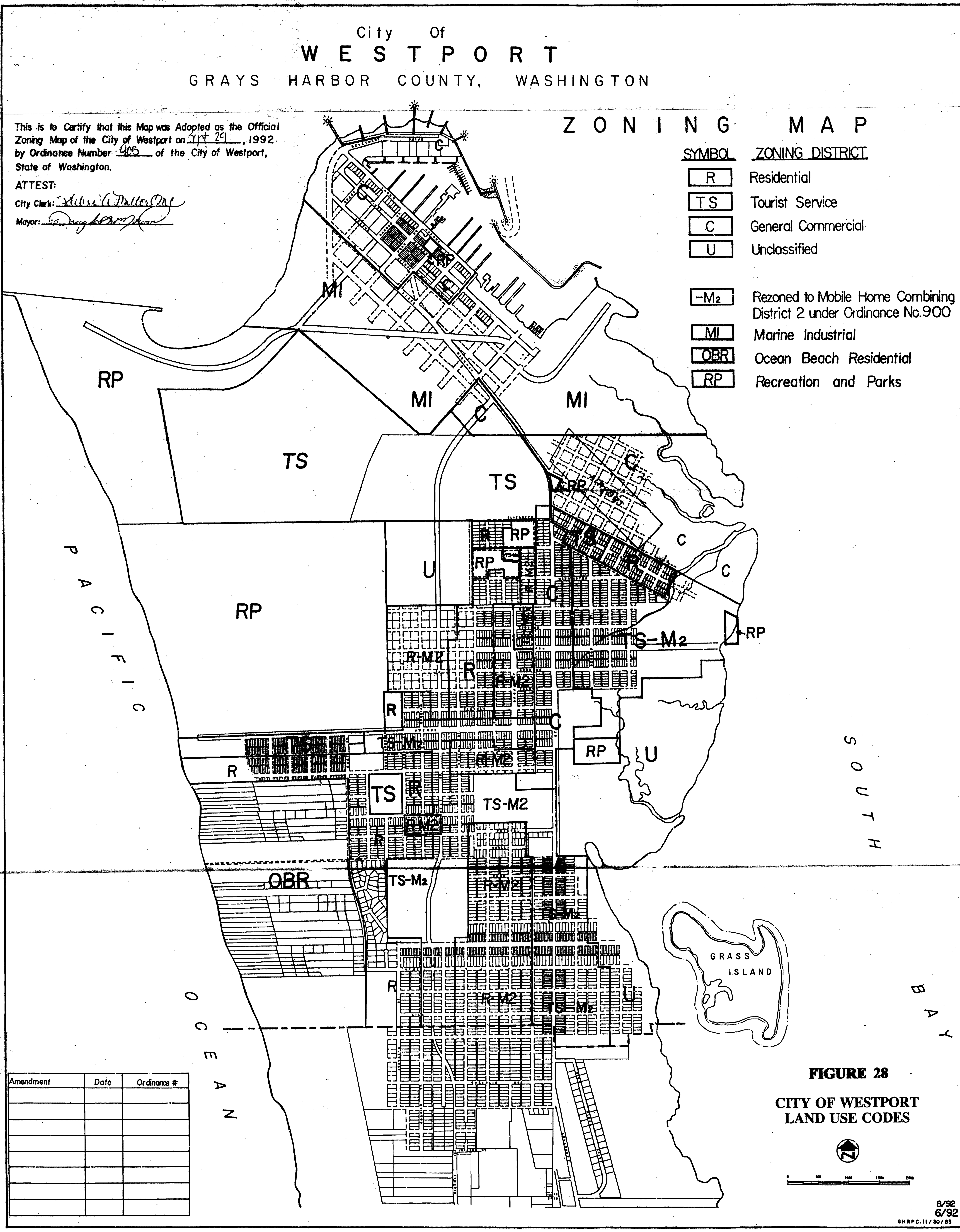
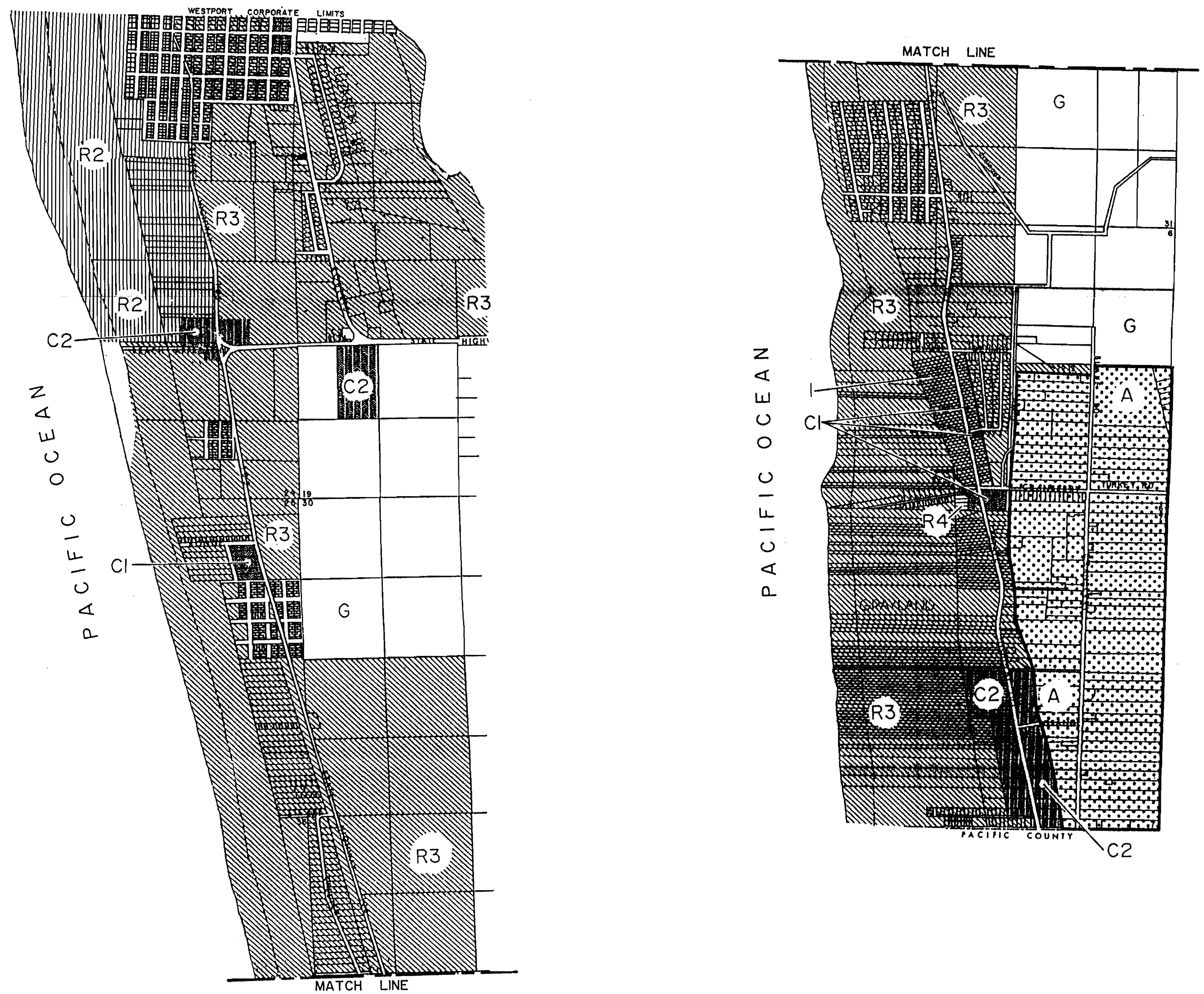


FIGURE 28

CITY OF WESTPORT LAND USE CODES



PRIMARY DISTRICTS

Description	Symbol	Minimum Subdivision
General Development	G	5 acres
Agricultural	A	10 acres
Agricultural - 1	A-1	10 acres
Agricultural - 2	A-2	40/10 acres
Residential (Restricted)	R-1	15,000 sq. ft.
Residential (General)	R-2	10,000 sq. ft.
Residential (Resort)	R-3	7,200 sq. ft.
Residential (Service)	R-4	10,000 sq. ft.
Commercial (Tourist)	C-1	NA
Commercial (General)	C-2	NA
Planned Shopping	C-3	NA
Industrial Park	I-1	NA
Industrial	I-2	NA
Manufacturing	M	NA

MAP COURTESY OF THE GRAYS HARBOR REGIONAL PLANNING COMMISSION

NO.	DATE	DESCRIPTION	APPROVED

REVISIONS

DESIGNED CLO
DRAWN KJD
CHECKED JLM
DATE 6/93

SCALE
NONE

CITY OF WESTPORT
COMPREHENSIVE WATER
SYSTEM PLAN

CONSOER TOWNSEND ASSOCIATES
ENGINEERING PLANNING MANAGEMENT

FIGURE 29
GRAYS HARBOR COUNTY
LAND USE CODES

CT&A PROJECT NO. 3816-00