CITY OF SALEM
DEPARTMENT OF PUBLIC WORKS

AQUIFER STORAGE AND RECOVERY IMPLEMENTATION PLAN

DRAFT
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Table of Contents

EXECUTIVE SUMMARY **ES-1**
BACKGROUND ES-1
ASR TESTING AND CONCLUSIONS ES-1
ASR FACILITY REQUIREMENTS ES-1
IMPLEMENTATION REQUIREMENTS ES-2

SECTION 1- INTRODUCTION **1-1**
BACKGROUND 1-1
OBJECTIVE 1-2
AUTHORIZATION 1-2
REPORT FORMAT 1-2
RELATED STUDIES 1-2
DEFINITIONS AND ABBREVIATIONS 1-3

SECTION 2- SUMMARY OF ASR TESTING AND CONCLUSIONS **2-1**
YEAR 1 ASR FACILITIES 2-1
Park Well No. 1 Monitoring Well 2-1
ASR Well No. 1 2-1
Computerized Water Level Logging Equipment 2-1
Groundwater Sampling Pumps 2-2
YEAR 2 ASR FACILITIES 2-2
ASR Well No. 2 2-2
Park Well No. 2 Monitoring Well 2-2
Landslide Monitoring Well No. 1 2-2
YEAR 1 ASR PILOT TESTING 2-3
Pumping and Injection Well-Capacity 2-3
Aquifer Storage Potential 2-3
Water Quality 2-4
YEAR 1 LANDSLIDE AREA INVESTIGATIONS 2-4
YEAR 2 EXISTING WELLS TESTING 2-5

SECTION 3- ASR FACILITY REQUIREMENTS **3-1**
PROJECT DEVELOPMENT 3-1
IMPACTS TO SYSTEM OPERATION 3-2
Operating Criteria 3-2
Distribution System Modeling 3-3
Initial System Operation Impacts 3-3
Long Term System Impacts 3-4
WATER QUALITY MONITORING PROGRAM 3-5
Water Quality Sampling Schedule for New Wells 3-5
Background Water Quality Sampling Schedule for Wells In Service 3-8
Water Quality Sampling During Withdrawal 3-8
LONG-TERM HYDROLOGIC MONITORING PROGRAM 3-10
Groundwater Level Monitoring 3-10
Surface Water Monitoring 3-10
Monitoring Plan and Periodic Reporting 3-11
WELLHEAD PROTECTION PROGRAM 3-11
Wellhead Advisory Committee 3-11
ASR Aquifer Computer Model 3-11
Contaminant Source Inventory Database 3-12
Spill Response Planning 3-12

Contingency Planning....3-12
Management Activities and Implementation....3-12
ASR SYSTEM DATABASE....3-12
SYSTEM OPERATION REQUIREMENTS....3-13
Well Performance Testing....3-13
Well Rehabilitation....3-13
PERMITTING REQUIREMENTS....3-13
Background....3-14
Limited License Application....3-15
Permanent ASR Water Rights....3-15
Waste Water Discharge Requirements....3-16

SECTION 4- IMPLEMENTATION REQUIREMENTS....4-1
WATER SUPPLY NEEDS....4-1
SUMMARY OF PROPOSED WATER SUPPLY FACILITIES....4-1
ASR Well Design Location and Withdrawal....4-1
Water Treatment....4-4
Distribution System Improvements....4-4
Pressure Reducing Stations....4-5
OTHER FACILITIES AND ACTIVITIES....4-6
Easements and Property Acquisition....4-6
Monitoring Wells....4-7
Long-Term Hydrologic Monitoring....4-7
Wellhead Protection Program....4-8
ASR System Database....4-8
Decision Flowchart....4-8
OPERATIONAL ISSUES....4-9
Water Quality Monitoring....4-10
Well Performance Testing and Rehabilitation....4-10
Peak Water Availability....4-10
Emergency Water Availability....4-11
PHASING AND SCHEDULE....4-11
IMPLEMENTATION COSTS....4-12
Capital Costs....4-12
Operational Costs....4-12
Other Program Costs....4-14

APPENDIX A - LIST OF REFERENCES
APPENDIX B - ASR GROUNDWATER SAMPLING PLAN

LIST OF TABLES

Table Number	Title	Page
3-1	ASR Implementation Plan: Water Quality Monitoring Program	3-6
3-2	ASR Implementation Plan: Water Quality Monitoring Program	3-8
4-1	ASR Water Supply Well Summary	4-2
4-2	ASR Implementation Cost Summary	4-13

LIST OF FIGURES

Figure Number	Title	Page
2-1	Vicinity Map and ASR Wells	2-1
2-2	Pilot Test Schedule	2-3
3-1	ASR Well Locations	3-1
4-1	ASR Water Supply Facilities	4-2
4-2	Schematic Typical Pressure Reducing Stations	4-5
4-3	ASR Water Supply Project Decision Flow Path	4-9
4-4	City of Salem Implementation Plan Schedule	4-11

Executive Summary

The Aquifer Storage and Recovery (ASR) Implementation Plan has been prepared to present a comprehensive plan for the City of Salem, such that the goals of the ASR water supply project can be met by July 1999. This Implementation Plan presents the requirements and a schedule of activities for completing the ASR water supply project by July 1999. This executive summary highlights key elements of the Implementation Plan.

BACKGROUND

- The ASR water supply project is a cornerstone of the City of Salem's *Water System Master Plan*, and is envisioned as providing both a secondary source of supply and additional distribution storage. The implementation of the ASR facilities has been scheduled to be complete over a five year period, with a supply capacity of 20 mgd and a 1 billion gallon storage capacity. The ASR water supply project was started in July 1994 and is scheduled to be complete by July 1999.

- Year 1 and Year 2 of the ASR water supply project included pilot testing of the ASR concept, groundwater level and water quality monitoring, and development of full scale ASR facilities. The goal at the completion of Year 3 is to have a supply capacity of 10 mgd on-line with 350,000,000 gallons of storage available. The remaining 10 mgd withdrawal rate and storage capacity of 650 MG is targeted to be on-line by July 1999.

- Presently two ASR well facilities have been constructed in Woodmansee Park providing a capacity of 4 mgd. ASR Well No. 1 is completely operational and has been receiving injection water and was also used for emergency supply in early 1996. ASR Well No. 2 is anticipated to be operational by mid-summer of 1996.

ASR TESTING AND CONCLUSIONS

- Results of the Year 1 testing indicated that the aquifer responded positively to the injection/extraction, and that water levels after injection were within the defined ASR permit limits.

- Results of withdrawal capacity testing at ASR Well No. 1 indicated that 1000 gpm to 1800 gpm is possible, and that greater withdrawal rates would most likely be achievable. Well hydraulics modeling results indicate that the aquifer in the vicinity of ASR Well No. 1 may accept 5,000 gpm of injection. In comparison to pumping, injection rates are able to exceed pumping rates.

- Both the groundwater and the surface water injection source have similar chemistries, and are identified as fresh waters with low mineral content and low hardness. Because of the similarities of the two waters, mixing (if it occurs) will not appreciably change the natural water chemistry of the groundwater.

ASR FACILITY REQUIREMENTS

- A total of six additional wells ranging in capacities from 600 gpm to 1000 gpm have been identified for completion by mid-April 1997. This would provide a total of 8 wells (2 existing and 6 new) for a combined projected withdrawal rate of 8000 gpm (11.5 mgd). Two of the new wells would be located in the future City park at Arlene Street with the remaining four wells being located within the boundaries of Woodmansee Park.

- Hydraulic modeling completed for the analysis of distribution of ASR supply water identified the need for a new water distribution pipeline from the vicinity of the existing ASR wells in Woodmansee Park extending west toward Liberty Street. The new pipeline will assist to distribute water during withdrawal and injection, and is needed at completion of the Year 3 ASR wells. Additional distribution piping has been identified for conveying water to the southern portions of the S-2 pressure zone. This pipeline would extend south from the Woodmansee Park ASR facilities to Boone Road.

- Once fully implemented the ASR system will have a capacity of 20 mgd which is in excess of the projected 14 mgd water demand for the S-2 pressure zone. This excess capacity can be used for meeting peak or emergency demands in other pressure zones. Pressure reducing stations at Mader, Fairmont and Boone Road booster pump stations will allow pressure reduction and direct bypass of the pumps into the lower pressure zones. An intertie between ASR Well Nos. 3 and 4 and the S-3 pressure zone is also planned to provide peak and emergency needs in that pressure zone.

- The long term water quality monitoring program of the ASR water supply program will establish a consistent and complete database for the evaluation of the effects of injection and withdrawal. The water quality monitoring program is subject to revision by the Oregon Water Resources Department, and is divided into three discrete phases: 1) new well on-line development, 2) background monitoring of existing wells, and 3) sampling during withdrawal.

- A long term hydrologic monitoring program is recommended to develop a complete database for determining the effects of the ASR program on groundwater and surface waters. Other activities recommended as part of the ASR water supply program include development and implementation of a Wellhead Protection Program and an ASR system database.

- A permanent ASR Water Right based upon a Limited License is the recommended approach for implementation of the ASR system. Currently, application for a Limited License for withdrawal of 20 mgd and storage of one billion gallons of water is pending approval with the Oregon Water Resources Department. Upon receipt of the Limited License the City will be able to operate the ASR system for the next five years, after which the City will need to apply for a permanent ASR Water Right. Additional permitting requirements related to discharge at well startup and during well rehabilitation wastewater discharge may require specific discharge permitting with the Oregon Department of Environmental Quality if conveyed to a storm sewer. Final conditions of the Limited License should be known in the Fall of 1996 and any changes to the plan described herein should be incorporated at that time.

IMPLEMENTATION REQUIREMENTS

- The ASR well facilities will be duplications of one another as architectural treatment permits. Each facility will include the well and valving and piping to existing distribution pipeline, and a masonry block well house which will house the well pump, well instrumentation and control, electrical components, a discharge to waste pipe, and a sodium hypochlorite disinfection system.

- Other facilities and activities required for completion of the ASR water supply project include easement/property acquisition for the Year 5 ASR wells, groundwater level monitoring wells, a long-term hydrologic monitoring program, a wellhead protection program, an ASR System Database, and a decision flowchart for tracking actual developed well capacity versus estimated well capacity and total capacity requirements.

- Operational issues associated with ASR water supply system include: implementation of the long term water quality monitoring program, well performance testing at the end of each year of operation and well rehabilitation as needed, and modification of current operation of supply to allow peaking and emergency supply from the ASR system.

- ASR Well Nos. 3 through 8 are scheduled for development and completion during Year 3, as is approximately 5,100 feet of distribution piping. Year 4 of the implementation plan consists of construction of an additional 6,900 feet of distribution system piping improvements and 3 pressure reducing stations, and property/easement acquisition. ASR Well Nos. 9 through 15 are scheduled to be developed and in-service by the end of Year 5 (July 1999).

- Total costs for the remaining ASR water supply facilities and activities identified in the Implementation Plan are approximately $8,100,000 to $8,950,000. A range of dollars is provided, because of the uncertainty associated with property acquisition. Total Year 3 costs are estimated at $3,900,000, Year 4 costs at $1,209,000 to $2,060,000, and Year 5 costs $3,124,000.

Section 1
Introduction

The City of Salem *Water System Master Plan* at the time of preparation in 1994, identified an immediate deficit in water supply capacity for the City. In response to the need for developing additional water supply, the City initiated the ASR water supply project. The Aquifer Storage and Recovery (ASR) water supply project is a cornerstone of the City of Salem's *Water System Master Plan* . The Master Plan identifies ASR as providing both a secondary source of supply and additional distribution storage.

BACKGROUND

The City of Salem plans that the ASR system will provide an alternate source of supply during peak or emergency conditions. The implementation of the ASR facilities has been scheduled to be complete over a five year period, ending in July 1999, and to cost approximately $10,000,000 to implement. The scope of work included in the ASR water supply project includes the following items:

- Engineering planning and design to evaluate the feasibility of ASR and for full scale implementation of the system.
- Evaluation of the aquifer through testing of existing wells and through the construction-equipping of new monitoring wells at selected locations.
- Construction of ASR wells within the Salem Heights aquifer which have common injection/extraction functions.
- Construction/equipping each well site with pump/motor, piping/valving, electrical/controls, building enclosure and water treatment facilities.
- Construction of necessary distribution system improvements to convey the ASR water supply.
- Long-term evaluation and monitoring of landslide potential along the western boundary of the ASR system including construction/equipping of new monitoring wells.
- Analyzing and recording groundwater and surface water quality prior to, during, and after construction of ASR facilities.

Year 1 (1994-1995) of the ASR water supply project completed the evaluation of the feasibility of the ASR water supply system. The initial results of the Year 1 testing indicated that the aquifer responded positively to the injection/extraction, and that water levels after injection were within the defined ASR permits limits. The goal of the Year 2 (1995-1996) ASR water supply project was to expand the system and provide a flow rate for peak supply needs of 4 mgd by July 1996. Year 2 also included aquifer testing, water level monitoring, water quality monitoring, and development of a landslide monitoring well.

To date, a total of to two wells have been constructed in Woodmansee Park with pump equipment, piping/valving, electrical and miscellaneous site improvements providing a capacity of 4 mgd. The first well (ASR 1) is completely operational and has been receiving injection water and also served as an emergency supply source. The second well (ASR 2) should be complete and operational during the summer of 1996 prior to the anticipated permit approval for a Limited License of operation from the Oregon Water Resources Department (OWRD). With the successful completion of Year 1 and Year 2 of the ASR water supply project, well sites and anticipated well withdrawal rates have been identified for the implementation of the full-scale ASR water supply project. The ASR Implementation Plan is completed in response to develop the ASR water supply project to a total water supply capacity of 20 mgd.

The City of Salem has elected to utilize the design and build services concept for development and implementation of the ASR water supply system. The design and build concept provides the City with the ability to accelerate construction of the facilities and complete implementation within the five year project schedule. In addition to schedule savings, costs savings are also realized from the design and build concept since a duplication of facility type will be performed at each of the well sites. The ASR Implementation Plan is designed to utilize the design and build concept, as well.

OBJECTIVE

The objective of the ASR Implementation Plan is to develop and present a comprehensive plan for the City for meeting the goals of the ASR water supply project in the desired time-frame. This plan presents the requirements of completion of the ASR water supply project and a schedule, which will ensure the completion of the ASR wells such that all wells will be fully operational by July 1999.

AUTHORIZATION

The Aquifer Storage and Recovery Implementation Plan has been completed in accordance with an agreement between the City of Salem and Montgomery Watson, dated October 3, 1994. Detailed hydrologic and technical analyses have been performed to achieve the objectives of this agreement and to conform to the Oregon Water Resources Department (OWRD) and Oregon Department of Environmental Quality (ODEQ) requirements for the ASR water supply project.

REPORT FORMAT

The four sections of this report summarize the background information, analyses, and recommendations for the ASR water supply project Implementation Plan. The four sections of the report are presented in a varying number of subsections. Subsection title hierarchy is indicated by typeface as follows:

FIRST LEVEL SUBSECTION HEADING

Second Level Subsection Heading

Third Level Subsection Heading

An executive summary is included to highlight the major findings and recommendations. More detailed information for certain elements of this study is presented in the Appendices.

RELATED STUDIES

The ASR water supply project is beginning its third year, which builds on the work completed during the past two years. Several studies and reports have been completed during the initial years of the ASR water supply project. These previous studies, reports, and agency guidelines influence the Implementation Plan for the ASR water supply project. To avoid duplication of effort, results of previous studies are integrated in the completion of this plan. Data collected and compiled as a part of the ASR water supply project provides the basis for the Aquifer Storage and Recovery Implementation Plan. Prior studies and data used to develop this Implementation Plan are identified in Appendix A.

DEFINITIONS AND ABBREVIATIONS

To conserve space and improve the readability of the text, the following abbreviations and definitions have been used in this report.

Ave	Avenue
ASR	Aquifer Storage and Recovery
ASR "#"	Aquifer Storage and Recovery Well No. "#"
AWWA	American Water Works Association
bgs	below ground surface
Blvd	Boulevard
btw	between
cfs	cubic feet per second
El	Elevation
EPA	U.S. Environmental Protection Agency
ft	feet
ft/d	feet per day
fps	feet per second
gpd	gallons per day
gpm	gallons per minutes
Hp	horsepower
hr	hour
in	inch
MG/mgal	million gallons
mg/l	milligrams per liter
mgd	million gallons per day
min	minute
NE	Northeast
No.	number
NW	Northwest
OHD	Oregon Health Division
ODEQ	Oregon Department of Environmental Quality
OWRD	Oregon Water Resources Department
ppm	parts per million
PRV	pressure reducing valve
psi	pounds per square inch
sec	second
SE	Southeast
SW	Southwest
State	State of Oregon

sq ft/sf	square feet
sq mi	square miles
TDH	Total dynamic head
TDS	total dissolved solids
µg/l	Microgram per liter
USGS	United State Geologic Survey
VOCs	Volatile synthetic organic chemicals
Wy	Way
WPCF	State Water Pollution Control Facilities
yr	year

Section 2
Summary of ASR Testing and Conclusions

Year 1 of the ASR project focused on a pilot test completed in a new well at Woodmansee Park and monitored in wells located throughout the ASR aquifer (Figure 2-1). Year 2 proceeded with additional testing and development for the full scale ASR system. In addition, during both Years 1 and 2, work was completed related to landslide issues on the western slope of the Salem Hills. This section summarizes the facilities, testing, and conclusions from this work.

YEAR 1 ASR FACILITIES

The Year 1 ASR facilities were provided to support the ASR pilot test. The ASR pilot test to-date is the most detailed investigation of ASR for the City. The purpose of the test was to evaluate the aquifer response to injection and pumping and associated water quality conditions. The facilities provided during Year 1 for the pilot test include the following:

Park Well No. 1 Monitoring Well

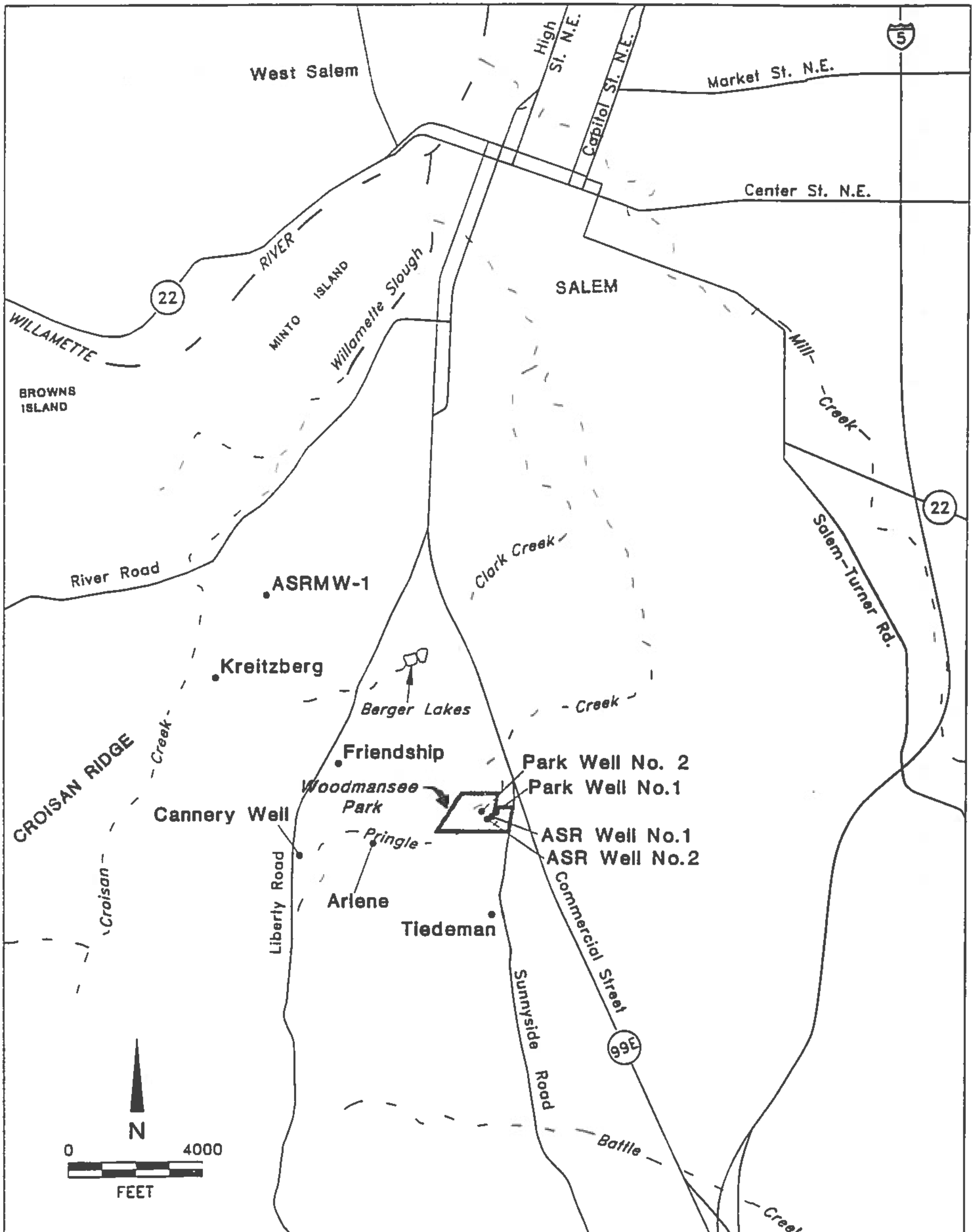
Park Well No. 1 was an existing well located in Woodmansee Park. Due to the earlier well construction, shallow groundwater was able to cascade down the borehole to the ASR aquifer. This condition was undesirable for monitoring and wellhead-protection purposes. To improve the well condition, Park Well No. 1 was retrofitted with 2-inch diameter PVC well casing and a slotted screen. The screen was open to the ASR aquifer and the remaining borehole above was sealed with grout materials preventing the vertical flow of groundwater. A detailed log of the monitoring well construction is provided in Golder (1995).

ASR Well No. 1

ASR Well No. 1 was the first newly completed well for the ASR project. ASR Well No. 1 is a dual purpose well that can be used for both pumping and injection. It is located in Woodmansee Park and is approximately 45 feet southwest of Park Well No. 1. ASR Well No. 1 was drilled during March 1995. It is 12-inch in diameter and extends for 316 feet below the ground surface. The well borehole is sealed by 12-inch diameter steel casing (1/4-inch wall thickness) grouted in place to a depth of 280 feet. Below the steel casing the well consists of an open borehole exposed to the basalt aquifer. A detailed log of the well construction and well performance testing is provided in Golder (1995). ASR Well No. 1 is equipped with a 150 hp line-shaft turbine pump set at approximately 265 feet below ground surface and capable of pumping 1,000 gpm. Injection through ASR Well No. 1 occurs down the pump column. The injection rate, which is approximately 900 gpm, is regulated by the distribution system pressure and frictional head loss through the well pump. The well and related piping is housed in a masonry block building, which includes a separated chlorine room.

Computerized Water Level Logging Equipment

One of the elements of the ASR pilot test was the evaluation of the aquifer pressure response to pumping and injection. In order to monitor this response, seven wells were selected and equipped with dedicated computerized water level logging equipment. These wells, which are shown on Figure 2-1, are referred to as: ASR Well No. 1, Park Well No. 1, Park Well No. 2, Arlene, Friendship, Tiedeman, and Krietzberg. The data logging equipment consists of a down-hole



EXPLANATION

Tiedeman • Well Location and Name

FIGURE 2-1
VICINITY MAP AND ASR WELLS
MW/SALEM ASR/OR

pressure transducer which connects by a cable to a data logger. The data logger is positioned in an accessible area at the top of the well. Water level measurements are automatically collected by the data logger according to a programmed frequency. The data are stored in the data logger computer memory and downloaded periodically for analysis and reporting. Each data logger unit is powered by a rechargeable sealed lead-acid, 6-volt battery.

Groundwater Sampling Pumps

In order to facilitate collection of groundwater quality samples during the pilot test, new sampling pumps were installed, as needed. Pumps were installed in Park Well No. 1, Park Well No. 2, Arlene, and Friendship. The Park Well No. 1 pump consisted of a 2-inch submersible with teflon discharge tubing. The other wells were equipped with 4-inch 1.5 hp submersible pumps with 1-1/4 inch galvanized discharge piping. Pump controls were included with each installation. Operation of the pumps requires a portable generator.

YEAR 2 ASR FACILITIES

Year 2 ASR facilities were constructed for the full scale ASR system. At the end of Year 1, the ASR pumping capacity, which consisted of only ASR Well No. 1, was 1.4 mgd. Following the positive results of the ASR pilot test, the City requested that the ASR pumping capacity be increased to 4 mgd. A new ASR well was installed during Year 2 for this purpose. In addition, two monitoring wells were completed that will be used for long-term monitoring. The Year 2 ASR facilities are summarized as follows:

ASR Well No. 2

ASR Well No. 2 is a newly installed dual purpose ASR well that can be used for both pumping and injection. The well is located approximately 20 feet west of ASR Well No. 1 in Woodmansee Park. ASR Well No. 2 was drilled during December 1995 at 16-inch diameter to a depth of 330 feet below ground surface. The borehole was lined to a depth of 280 feet below ground surface with steel casing (3/8 inch wall thickness) grouted in place. Below the casing the well is an open hole exposed to the basalt aquifer. A detailed log of the borehole and a discussion of the well performance testing is provided in Golder (1996a). Completion of ASR Well No. 2 is in progress. The well is expected to be operational during August 1996. The completion will include a line-shaft turbine pump and 300 hp motor with a capacity of 1,800 gpm. The well will be housed in a masonry block building with a common wall to the ASR Well No. 1 building.

Park Well No. 2 Monitoring Well

Park Well No. 2 is an existing water well located about 440 feet west of ASR Well No. 1 in Woodmansee Park (Figure 2-1). Due to earlier construction, shallow groundwater cascades down the borehole to the ASR aquifer. This condition was undesirable for monitoring and wellhead protection purposes. To improve the well condition, Park Well No. 2 was retrofitted with 4-inch diameter PVC casing with a slotted screen open to the ASR aquifer. The borehole above the screen was grouted to prevent vertical flow of groundwater. The original sampling pump in the well was replaced with a 2-inch submersible pump with a teflon discharge tube. A detailed log for the monitoring well construction is provided in Golder (1996b)

Landslide Monitoring Well No. 1

Landslide deposits are known to exist along the west slope of the Salem Heights aquifer, above the Willamette River. Due to the potential for ASR to increase groundwater pressure, investigations have been conducted to assess if ASR operations could destabilize the existing landslide deposits. In support of these evaluations and for long-term monitoring, a new monitoring well was constructed. The monitoring well, designated ASRMW-1, is located in the right-of-way along Dogwood Drive South. The monitoring well was constructed with 2-inch diameter PVC casing with a slotted screen located between 40 and 50 feet below ground surface. The screen is located at the base of the landslide deposits. The well is completed with a flush, watertight, bolted utility vault monument and is equipped with a computerized water level recording instrument. A detailed log of the monitoring well is provided in Golder (1996f).

YEAR 1 ASR PILOT TESTING

The ASR pilot test was completed during the summer and fall of 1995 and used ASR Well No. 1 for injection and pumping. The pilot test included several testing phases that are shown on Figure 2-2. The most important testing phases included: 1) 30-days of injection (38,315,700 gallons); 2) 60-days of storage in the aquifer; and 3) 30-days of pumping (36,925,700 gallons) following the storage period. Aquifer water levels and water quality were monitored throughout the testing period. Detailed discussion and presentation of the project data is provided in Golder (1996c, 1996d). The results of the testing are summarized as follows:

Pumping and Injection Well-Capacity

Because the ASR pilot test was limited to ASR Well No. 1, specific conclusions regarding pumping and injection rates are only applicable to the area of this well. The rate of pumping is limited by the equipment installed in the well. ASR Well No. 1 pumping capacity is 1,000 gpm. ASR Well No. 2, which is installed within 20 feet of ASR Well No. 1, has a design pumping capacity of 1,800 gpm. Thus, the total pumping capacity at Woodmansee Park from both wells is 2,800 gpm, or 4 mgd. The aquifer at this location can likely be pumped at larger rates, possibly in excess of 4,000 gpm.

The possible injection rate at Woodmansee Park in ASR Well No. 1 is limited by the equipment in the well and the distribution system pressure. During the ASR pilot test, the average rate of injection was 887 gpm over the 30-day injection period. Based on design data, it is expected that ASR Well No. 2 could inject an additional 1,500 gpm. Thus, the total injection capacity for the present system would be 2,387 gpm, or 3.4 mgd. Well hydraulics modeling results indicate the aquifer may accept 5,000 gpm of injection and possibly more in the vicinity of ASR Well No. 1. In comparison to pumping, the available aquifer buildup exceeds the available drawdown, thus, injection rates are able to exceed pumping rates.

Aquifer Storage Potential

The injection of water into the aquifer results in buildup of the aquifer pore pressure. The pressure buildup allows water to be stored in the aquifer by expanding the rock matrix and compressing the water. The storage in the aquifer was analyzed based on the ASR pilot test. Well hydraulics modeling based on the ASR pilot test data was used to predict possible injection volumes. Based on this modeling, it appears 350 MG can be injected without excessive buildup of aquifer pressure. It is possible that up to 525 Mgal could be injected. In a full scale ASR system, the injection volume may be increased to 1,000 MG. Aquifer testing, which will occur throughout the development phase of the ASR system will be used to assess injection potential and refine these preliminary estimates.

The efficiency of the aquifer to store injected water depends on the specific ASR cycle (i.e., the duration and rate of injection, the duration of the storage period, and the duration and rate of the pumping period). The efficiency of the ASR pilot test was estimated at about 75%. There is

Test Description	Start	Finish
4-hour Pumping Test	3/31/95	3/31/95
24-hour Constant Rate Pumping Test	6/26/95	6/27/95
4-hour Step Injection Test	6/28/95	6/28/95
30-day Constant Rate Injection Test	6/29/95	7/28/95
60-day Storage Period	7/29/95	9/27/95
4-hour Step Pumping Test	9/28/95	9/28/95
30-day Constant Rate Pumping Test	9/29/95	10/25/95
30-day Recovery Period	10/26/95	11/29/95

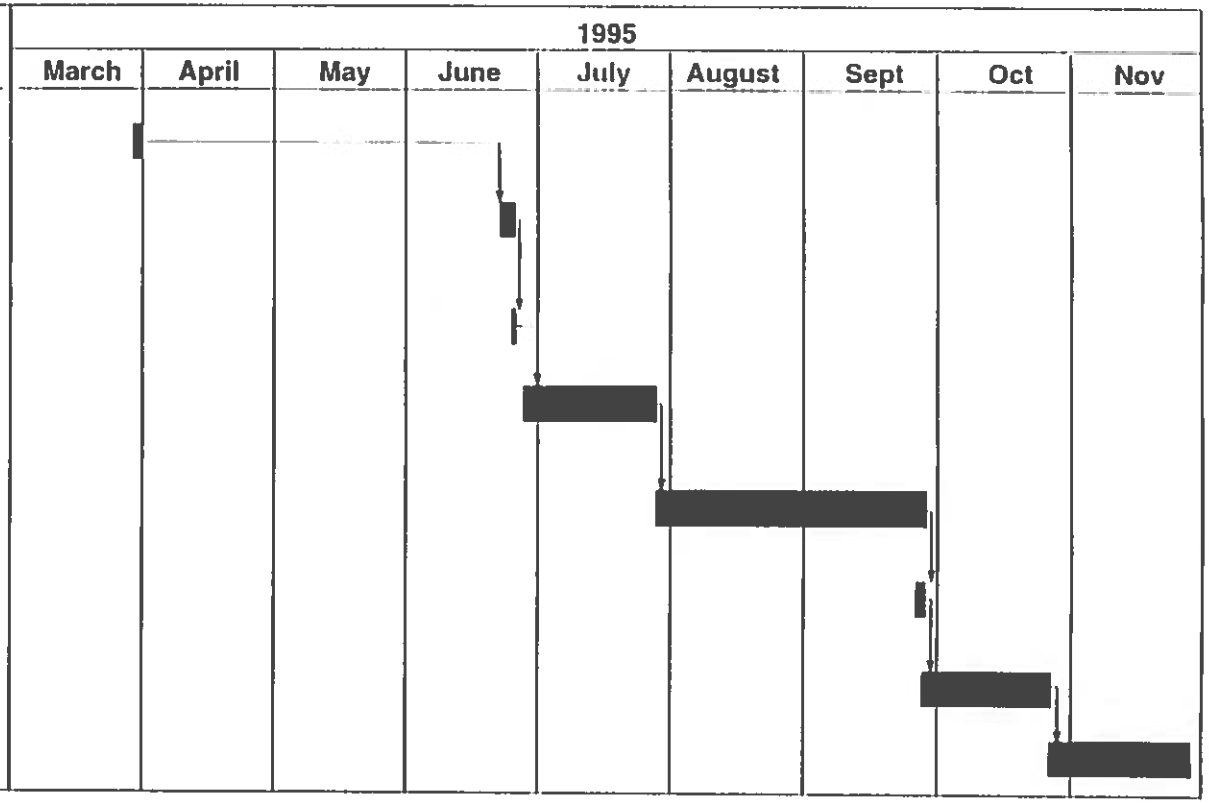


FIGURE 2-2
PILOT TEST SCHEDULE
MW/SALEM ASR/OR

PROJECT NO. 943 1653.601 DRAWING NO. 66831 DATE 6/17/96 DRAWN BY TK

Golder Associates

uncertainty associated with this efficiency estimate, however, and the actual efficiency could be slightly lower or much higher (56% to 99%). In general, the results of the pilot test were highly favorable, with aquifer buildup levels dropping at a rate of approximately 0.0007 ft/d at the end of the storage period. The aquifer buildup level had generally stabilized at 4 to 5 feet above the pre-injection level.

Water Quality

Water quality was an important aspect of the ASR pilot test. With respect to regulations, there was concern over the possible introduction of contaminants into the aquifer due to injection. It was also necessary that the ambient groundwater meet drinking water standards, should this water mix substantially with the injected water. With respect to ASR system operation, there was a need to identify if aquifer clogging, due to mixing reactions and suspended solids, would be an important problem. Up to 32 groundwater samples were collected from six wells during different phases of the pilot test. Sample analysis included a comprehensive suite of organic, inorganic, and water quality constituents. These analyses were summarized and contained in a technical memorandum (MW, 1996) prepared during Year 2 of the project.

The data were subsequently evaluated with respect to the water quality issues. Both the groundwater and the surface water injection source have remarkably similar chemistries. Thus, mixing the two waters does not appreciably change the water chemistry. Both are considered fresh waters with low mineral content and consequently low hardness. Both waters also are free of contamination by organic compounds that would be regulated in native groundwaters or public drinking water supplies. Regulated inorganic constituents are also measured at levels below regulatory criteria or were not detected in the samples.

With regard to aquifer clogging, the injection process has a potential to develop precipitation of iron-hydroxide minerals. Upon review of the water quality data, the iron concentration of the groundwater is low and the precipitation of iron-hydroxide minerals is expected to be minimal. Thus, aquifer clogging due to a precipitation mechanism is unlikely. The injection source water, however, contains suspended solids which in time will be deposited in the aquifer. During pumping, some of these solids are removed. However, it is anticipated that on a periodic basis, well rehabilitation will be needed to remove particles and restore well efficiency.

YEAR 1 LANDSLIDE AREA INVESTIGATIONS

Landslide deposits along the west slope of the Salem Heights area overlie the native bedrock materials. At the initiation of the ASR project, it was not known if the ASR aquifer extended to and contacted the landslide deposits. In such a situation, it may be possible for the injection of water into the aquifer to increase pore pressures in the landslide deposits resulting in a destabilized condition. An evaluation of the relation between the ASR aquifer and the landslide deposits was conducted. This evaluation consisted of reviewing existing information, field mapping of the landslides, and monitoring of groundwater levels in the landslides. Details of this work are presented in Golder (1996e).

The results of this work indicate that the ASR aquifer and the landslide deposits are not in contact within the area of the investigation. Based on the presently available data, injection of water into the ASR aquifer will not destabilize the landslide deposits. During the implementation of the full scale ASR system, additional landslide monitoring wells are to be installed. These wells will be used for long-term monitoring of groundwater levels in the landslide deposits.

YEAR 2 EXISTING WELLS TESTING

Part of the Year 2 work focused on gathering information on the aquifer outside of the Woodmansee Park area. This information will be used to support decisions regarding future ASR well locations and anticipated injection/pumping rates. To obtain this information in a cost effective manner, well tests were conducted in the existing Arlene, Cannery, and Friendship Wells (Figure 2-1). Geophysical logging of the boreholes was conducted in each of the wells. The Arlene and Cannery Wells were also used to conduct aquifer pumping tests. Due to its small diameter and proximity to power lines, the Friendship Well was not used for a pumping test. Details on the testing and results are a presented in Golder (1996g).

The results of the testing indicate that each well penetrates to the basalt aquifer. The Friendship Well appears to penetrate only the uppermost few feet of the aquifer. The Arlene and Cannery wells extend completely through the aquifer to underlying materials. The hydraulic properties of the aquifer appear to deteriorate from Woodmansee Park to the Arlene Well. The aquifer transmissivity at the Arlene Well is 2/3 of that at Woodmansee Park and the Cannery Well 1/6 of Woodmansee Park. ASR wells could be installed in proximity to both locations, however, the pumping/injection rates are expected to range from 500 to 1,000 gpm.

Section 3
ASR Facility Requirements

The City of Salem initiated the aquifer storage and recovery (ASR) project to provide supplemental water supply for meeting summer peak demands and emergency conditions. The program was developed with a 5 year time schedule for implementation. At the time of writing this report the City is completing the second year of the program and has made application for a Limited License with the Oregon Water Resources Department for up to 1.0 billion gallons of storage, and a withdrawal rate of 20 mgd to meet the projected peak or emergency demands.

This section provides an overview of ASR system storage and withdrawal requirements for complete buildout. In addition, a description of water distribution system requirements due to ASR development are provided including a discussion of system modeling conducted to verify specific distribution system needs. Near and long-term operational aspects of the ASR system are discussed. Water quality monitoring for the ASR implementation and operation is discussed. Long-term hydrologic monitoring and system operation requirements are also discussed. Finally, permitting requirements for total development of the ASR system are presented.

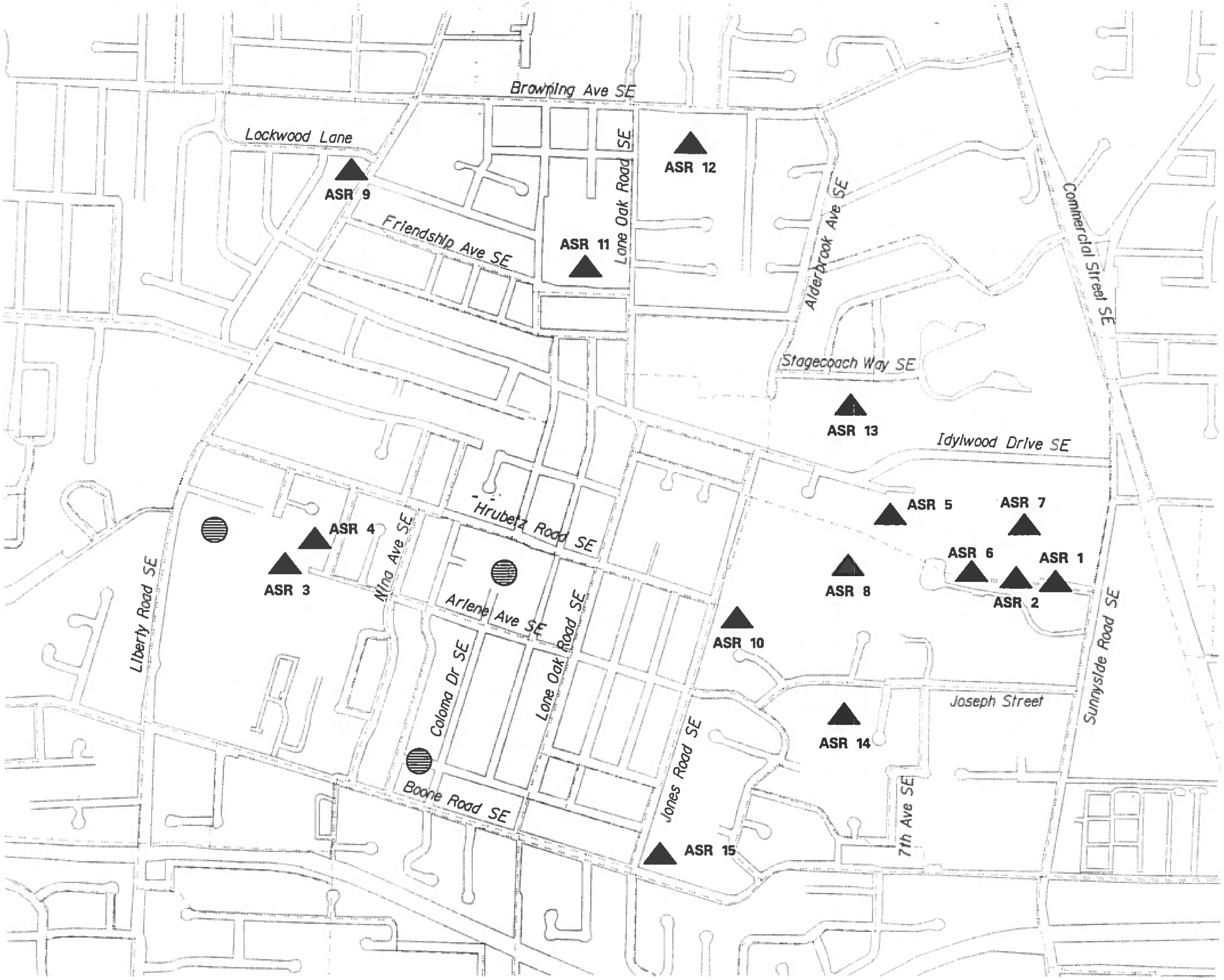
PROJECT DEVELOPMENT

The following paragraphs provide an overview of the full scale ASR system development and a brief description of proposed facilities. A more detailed discussion of future facilities is contained in this section and Section 4.

The ASR system currently consists of two wells located within Woodmansee Park in the south Salem area. The two wells have a combined design capacity of 2800 gpm (4 mgd). Based on projected needs from the ASR system, the City desires a storage capacity of 350 million gallons (MG) by the summer of 1997 and a minimum withdrawal rate from storage of 10 mgd. The summer of 1997 is also within Year 3 of the ASR program. Based upon the time period required for construction of the wells and for injection of water for storage prior to July 1997, the facilities would need to be completed and permitted by the spring of 1997. A total of six (6) additional wells would be constructed with location and projected individual capacities as shown on Figure 3-1. This would provide a total of 8 wells (2 existing and 6 new) for a combined projected withdrawal rate of 8000 gpm (11.5 mgd).

Six of the wells constructed during Year 3 of the program would be located within the boundary of Woodmansee Park. The remaining two wells would be located near Liberty Street at Arlene Park to assist in facilitating delivery of water to the S-3 pressure zone. Aside from the operational advantages of these well locations, they are also located on property owned by the City, eliminating potentially lengthy acquisition, and would allow construction to be completed within the Year 3 time period. In addition to the wells, a new water distribution pipe would also be added from the vicinity of the existing ASR wells in Woodmansee Park and extend west toward Liberty Street. The new pipeline will assist to distribute water during withdrawal and injection.

During Year 4 of the ASR program, which would occur during the 1998 calendar year, the City would desire to add storage to the system in the amount of 350 MG for a total ASR system storage of 700 MG. No additional wells would be constructed during this period, however the securing of property at the proposed Year 5 well locations would be completed. In addition to the proposed sites, optional sites would also be explored and secured should the development of individual wells not produce the estimated capacities. These optional sites are illustrated on Figure 3-1. Each of the new and optional sites are currently under private ownership or owned by public/private schools.



LEGEND

- ▲ ASR WELL LOCATIONS
- ◍ OPTIONAL ASR WELL LOCATIONS
- ········ EXISTING PIPING

ASR WELL NO.	CAPACITY (GPM)	APPARENT PROPERTY OWNERSHIP
ASR 1	1000	CITY
ASR 2	1800	CITY
ASR 3	600	CITY
ASR 4	600	CITY
ASR 5	1000	CITY
ASR 6	1000	CITY
ASR 7	1000	CITY
ASR 8	1000	CITY
ASR 9	1000	PRIVATE
ASR 10	1000	SCHOOL
ASR 11	600	SCHOOL/PRIVATE
ASR 12	600	SCHOOL
ASR 13	1000	PRIVATE
ASR 14	1000	PRIVATE
ASR 15	600	PRIVATE

Base mapping provided by the City of Salem.

ASR Well Locations
Figure 3-1

MONTGOMERY WATSON

These sites would be available for construction of additional wells should they be necessary for meeting the ultimate demands of the ASR system in Year 5.

The ASR water supply project would be completed by the summer of Year 5 or July 1999 with an additional 300 MG of storage provided and an additional seven (7) wells constructed. This would provide total storage of 1.0 billion gallons for meeting peak and emergency water demands. The withdrawal rate from the 13 individual ASR wells would be projected at 13,800 gpm (19.87 MGD). Specific location of the Year 5 wells is also shown on Figure 3-1.

Operation of the ASR system is to meet the peak or emergency demands that occur during each year of the program. Should the climatic conditions and system demands not require ASR supply for peaking or emergency conditions, the water placed in storage will remain until such time that demand or conditions warrant.

IMPACTS TO SYSTEM OPERATION

The ASR system as it is developed will impose unique impacts on the distribution system. The well locations and subsequent storage is located within pressure zone S-2 which is the third highest pressure zone in the City system, above pressure zones G-O and S-1. Water supply is conveyed to zone S-2 from three input locations including the Boone Road, Fairmont and Edwards pump stations. These facilities boost water from zone G-O into zone S-2 and will be the source of supply to the ASR wells during injection and storage occurring in the off-peak demand periods. Once the ASR system is developed, the ASR system will provide supply to all of the City pressure zones for peak demand periods and as an emergency supply.

The original City distribution system was not designed or configured to have a source of water supply contained within the S-2 pressure zone. Therefore, when water demands are to be met in zones other than S-2 from the ASR supply, water will move through the distribution system unique to the original system design. One objective of this implementation plan is to evaluate the impacts of the ASR supply system operation on the distribution system and identify any remedies which are necessary to maintain acceptable operation.

Operating Criteria

There are three specific operating criteria to be provided by the ASR system which include 1) ability to meet the operating system pressure of the zone, 2) provide a source of supply to all City pressure zones during peak demand periods, and 3) provide an emergency supply source to all City pressure zones. The desired maximum operating pressure within the S-2 pressure zone is less than 100 psi. However, there are some areas of the S-2 system, specifically along Boone Road and east of Sunnyside Road which have pockets of high system operating pressure. The City has had to install individual pressure reducing valves on residences in these areas to protect plumbing fixtures from pressures which might exceed 100 psi and cause damage. Operation of the ASR facilities should not elevate system pressures greater than the 100 psi criteria within the S-2 pressure zone.

Distribution of water from zone S-2 to lower pressure zones G-0 and S-1 and upper zone S-3 is desired to meet the peaking and emergency supply criteria. The ability to distribute ASR water supply to the entire City system at a rate of 20 mgd is required once the entire ASR system is on-line at the end of Year 5 of the ASR implementation program.

Distribution System Modeling

Based upon the operating criteria described in previous paragraphs, the City assisted in evaluating the distribution system impacts through use of the computer model, NETWK PC, which was prepared as part of the City of Salem *Water System Master Plan*. Several operational scenarios were developed for the modeling work to evaluate system deficiencies related to the specific operating criteria. In general, if a deficiency was noted, then pipe additions were incorporated and the model rerun to evaluate the effectiveness of the proposed improvement.

Prior to conducting the modeling, a system calibration was performed by City staff. This consisted of simulating a peak demand condition within zone S-2 with designated booster pumps at the Edwards, Boone Road, and Fairmont pumping stations in operation, preset water levels in Kurth, Seeger and Chacarun reservoirs, and pressure recording at numerous locations throughout the zone. Results from the field test compared to a modeling run under identical conditions were very successful. In general, similar pressures were calculated with the model compared to the field test data. Based upon these results, further modeling was performed to evaluate system operation with increasing input from ASR facilities.

Modeling runs were prepared evaluating the following variable conditions:

- 1996 and ultimate system peak day demands.
- Increasing ASR input from 1000 gpm up to 14,000 gpm.
- S-2 source outputs to G-0 at simulated Boone Road and Mader Bypasses.
- S-2 source output to S-3 with pipeline dedicated to the vicinity of the Skyline pump station.
- S-2 source output to S-1 with simulated Mader Bypass.
- Varying outputs from S-2 reservoirs.

Acceptable results from the model were identified for ultimate ASR system capacity and corresponding system demands. Proposed distribution system improvements were verified through these modeling efforts and are described in following sections of this Plan.

Initial System Operation Impacts

Following implementation and startup of ASR Well No. 1, it was observed that under specific distribution system operating conditions, high pressure within zone S-2 was occurring. Initially, this was detected by observing that ASR Well No. 1 had shut down due to high discharge pressure. A pressure recorder was installed and this data logged pressure spikes within S-2 which corresponded to altitude valve closures at Kurth and Seeger reservoirs. The Booster pump at Boone Road was also supplying water to S-2 at this time.

The conditions created by this operating scenario result from supply entering the S-2 zone in excess of water demands within the S-2 zone. As a result, the reservoirs fill and system pressure is at its highest. With continuing operation of the supply sources with full reservoirs, the pressure continues to increase until the source is shut-off. This condition was simulated in the City modeling effort and a system pressure of 124 psi was calculated at the vicinity of ASR Well No. 1 which verified the condition.

Following review of this condition, it was determined that an operational remedy was needed to control ASR Well No. 1 to allow operation without shutdown under high system pressures. It should be noted that high pressure is not sustained for long periods and represent spikes for periods of only approximately 30 minutes. The City sought a remedy which would allow ASR pumps to continue operating and not require manual startup following a high pressure shutdown. Therefore, a solution which incorporates a pressure sustaining valve on the ASR pump discharge was developed. The valve senses system pressure and restricts the pump output to a set maximum pressure. As a result, the pump is effectively moved to the left on its corresponding system curve delivering less flow under high distribution system pressures. It is estimated that the maximum reduction in flow would decrease to approximately 600 gpm prior to reaching a shutdown condition.

The pressure sustaining valve provides operational control of the ASR pumps and allows them to continue operating during high system pressure peaks. This however is only a partial solution to a longer term issue. If additional supply is provided from the ASR source while traditional sources of supply from the existing booster pumps are also operated in zone S-2, and system demands are less than the sum of these supplies, high system pressures will continue. The remedies for this condition are described in the following section regarding long term system impacts.

Long Term System Impacts

As noted in the previous paragraphs, as additional supply is introduced into the S-2 zone from the ASR source concurrent with surface water supply provided by booster pumping, and zone S-2 demands are less than this supply, system pressures will increase. The ultimate solution to this condition involves several remedies. However, the basic solution involves matching supply to demand. The ideal situation is to operate ASR supply as a replacement for traditional supplies brought into S-2 from the booster pump stations. This in essence provides an excess of surface supply which can be distributed to the other pressure zones. As the ASR system is fully implemented however, it will have a capacity (20 mgd) which is greater than the projected S-2 demands (14 mgd) and an over supply surplus will occur. The remedy for this later condition will be to convey ASR supply outside of zone S-2 to the other pressure zones. In addition, some distribution system additions have been identified to convey the ASR water supply within zone S-2, and to points where it can be sent to other pressure zones.

The strategy in developing additional ASR supply will be to have combinations of ASR pumps/wells which match the booster pump capacity combinations provided from the Boone Road, Edwards and Fairmont pump stations. For example, if the largest Boone Road booster pump has a capacity of 4000 gpm, then an identical combination of ASR pumps should be available to deliver the same rate such that the Boone Road pump can be shut off and the ASR supply turned on to meet equivalent demand in zone S-2. This will maintain system delivery under similar conditions to that provided by the existing booster pumps.

The need for additional distribution system piping within zone S-2 is to assist in distributing the ASR supply. This piping will also assist in reducing system pressure through more uniform distribution of flows within the S-2 pressure zone. The major piping addition which was confirmed by the distribution system modeling includes approximately 5,000 feet of 16-inch pipeline extending from Woodmansee Park directly west to Hrubetz Road SE. A more detailed description of this facility is provided in Section 4 of this Plan.

Another distribution system improvement is recommended to assist in distributing ASR flow to the southeast area of zone S-2. This improvement would include a 16-inch pipeline extending south from Woodmansee Park roughly traversing Tragen Court, Boxwood Lane and 7th Avenue SE. A more detailed illustration of this recommendation is provided in Section 4.

Finally, in order to distribute ASR water supply to other pressure zones, modifications will be necessary in the vicinity of the Edwards, Fairmont and Boone Road booster pump stations to allow pressure reduction and direct bypass of the booster pumps into the lower pressure zones. These modifications are described in Section 4. The ability to supply the higher pressure zone S-3 will be met by providing a dedicated supply pipe from ASR supply facilities located near Liberty Road and extending to the vicinity of the Skyline booster pump station. These facility additions are also described in Section 4.

These long term system improvements and addition of ASR supply facilities will allow the City to meet peaking and emergency supply requirements which form the basis of the ASR supply.

WATER QUALITY MONITORING PROGRAM

The long term water quality monitoring program will build on previous sampling work performed as part of the recently completed ASR Pilot Test Project. The 1995 ASR Pilot Test Project established baseline ground water quality conditions and evaluated water quality at critical points in the pilot program. The continuation of this work during the implementation phase of the ASR water supply program will establish a consistent and complete database for the evaluation of the effects of injection and withdrawal.

The following water quality sampling program and list of parameters is subject to revision based on OWRD comment and direction. An application to OWRD for the Limited License which requires specific water quality monitoring requirements is pending at the time of this writing. The approved OWRD permit will contain specific sampling requirements for water quality monitoring. The sampling program described below is based on discussions with OHD staff, and in general is much more extensive than was required by ODEQ in the 1995 ASR Pilot Test project.

As described elsewhere in the Implementation Plan, a total of 15 wells will be brought on-line over the five year period of the ASR program. All of these wells may serve as both injection and withdrawal points. In general, sampling will focus on three discrete phases of well operation:

1) bringing a new well on-line;
2) background monitoring on existing wells; and
3) sampling during withdrawal .

Water Quality Sampling Schedule for New Wells

Additional wells will be installed in the Salem Heights Aquifer during the last three years of the ASR implementation program. Before a new well is used for injection or withdrawal, three background water quality samples will be collected and analyzed for the physical parameters, nutrients, inorganic and organic chemicals and radon, as listed in Table 3-1. If no contaminants are detected at levels of concern, that well will be brought on-line.

Table 3-1
City of Salem
ASR Implementation Plan: Water Quality Monitoring Program

Conventional Parameters

- Conductivity
- *Conductivity (Field Data)*
- pH
- *pH (Field Data)*
- *Temperature (Field Data)*
- Total Dissolved Solids
- Turbidity
- *Turbidity (Field Data)*
- *Dissolved Oxygen (Field Data)*
- *Oxygen Reduction Potential (Field Data)*
- Chloride
- Silica
- Nitrite (as N)
- Total nitrate & nitrite
- Sulfate
- Nitrate (as N)
- Fluoride (free)
- Total Alkalinity
- Carbonate Alkalinity
- Hydroxide Alkalinity
- Bicarbonate Alkalinity
- Carbon Dioxide
- Total Phosphate
- Iodide
- Total Trihalomethanes

Color
Corrosivity
Foaming agents
Odor

Microbiological

- Standard Plate Count
- Total Coliform
- Fecal Coliform

Metals

- Barium
- Calcium
- Copper
- Iron
- Magnesium
- Manganese
- Potassium
- Sodium
- Zinc
- Total Hardness
- Antimony
- Asbestos
- Arsenic
- Cadmium
- Chromium
- Lead
- Mercury
- Selenium
- Silver
- Beryllium
- Cyanide
- Nickel

Thallium
Aluminum

Radionuclides

- Radon (Rn-222)
- Gross alpha & beta

Combined Radium-226 and Radium-228
Iodine-131
Strontium 90
Tritium

Extractable Organics

- 1,2-Dibromoethane
- 1,2-Dibromo-3-chloropropane
- Hexachlorocyclopentadiene
- Alachlor
- Aldrin
- gamma-BHC (Lindane)
- 1,2-Dichlorobenzene
- 1,3-Dichlorobenzene
- 1,4-Dichlorobenzene
- Dichlorodifluoromethane
- 1,1-Dichloroethane
- 1,2-Dichloroethane

o-Dichlorobenzene
p-Dichlorobenzene

Table 3-1 - continued
City of Salem
ASR Implementation Plan: Water Quality Monitoring Program

Extractable Organics

Chlordane
Dieldrin
Endrin
Heptachlor
Heptachlor epoxide
Hexachlorobenzene
Methoxychlor
Toxaphene
Polychlorinated Biphenyls
Aroclor 1242
Aroclor 1248
Aroclor 1254
Aroclor 1260
Benzene
Bromobenzene
Bromochloromethane
Bromodichloromethane
Bromoform
Bromomethane
n-Butylbenzene
sec-Butylbenzene
tert-Butylbenzene
Carbon tetrachloride
Chlorobenzene
Chloroethane
Chloroform
Chloromethane
2-Chlorotoluene
4-Chlorotoluene
Dibromochloromethane
1,2-Dibromo-3-chloropropane
1,2-Dibromoethane
Dibromomethane
Atrazine
Benzo(a)pyrene
Carbofuran
Dalapon

1,1-Dichloroethene
cis-1,2-Dichloroethene
trans-1,2-Dichloroethene
1,2-Dichloropropane
1,3-Dichloropropane
2,2-Dichloropropane
1,1-Dichloropropene
cis-1,3-Dichloropropene
trans-1,3-Dichloropropene
Ethylbenzene
Hexachlorobutadiene
Isopropylbenzene
4-Isopropyltoluene
Methylene chloride
Naphthalene
n-Propylbenzene
Styrene
1,1,1,2-Tetrachloroethane
1,1,2,2-Tetrachloroethane
Tetrachloroethene
Toluene
1,2,3-Trichlorobenzene
1,2,4-Trichlorobenzene
1,1,1-Trichloroethane
1,1,2-Trichloroethane
Trichloroethene
Trichlorofluoromethane
1,2,3-Trichloropropane
1,2,4-Trimethylbenzene
1,3,5-Trimethylbenzene
Vinyl chloride
m,p-Xylene
o-Xylene
Endothall
Ethylene Dibromide
Glyphosphate
Heptachlor epoxide

Table 3-1 - continued
City of Salem
ASR Implementation Plan: Water Quality Monitoring Program

Extractable Organics

Dibromochloropropane
Dinoseb
Dioxin
Diquat
Di(2-ethylhexyl)adipate
Di(2-ethylhexyl)phthalate
Oxamyl (Vydate)
Picloram
Pentachlorophenol
Simazine
2,4-D
2,4,5-TP Silvex

Background Water Quality Sampling Schedule for Wells In Service

Wells which are operational but which are not being used for withdrawal will be monitored for physical parameters, nutrients, inorganic and organic chemicals as described in Table 3-2. These wells will be monitored once every three years. If a well is used for withdrawal during this three year period, then additional water quality monitoring must occur as described in the next section.

Water Quality Sampling During Withdrawal

One sample will be collected during the first 48 hours of withdrawal at each applicable well, and analyzed for the parameters described in Table 3-2. A follow-up water quality sample will be collected after six weeks of pumping, if the well continues to be in-service, and analyzed for the parameters listed in Table 3-2.

Samples will be analyzed by a certified laboratory. Field parameters will include conductivity, pH, temperature, turbidity, dissolved oxygen and redox potential. Field measurements will be taken at the time of sampling. Samples will be collected and handled according to procedures described in *Aquifer Storage and Recovery Pilot Project, Groundwater Sampling Plan* (Montgomery Watson, 1995). The sampling plan is included in Appendix B.

Table 3-2
City of Salem
ASR Implementation Plan: Water Quality Monitoring Program

Conventional Parameters

Conductivity
Conductivity (Field Data)
pH
pH (Field Data)
Temperature (Field Data)
Total Dissolved Solids
Turbidity
Turbidity (Field Data)
Dissolved Oxygen (Field Data)

Metals

Copper
Iron
Manganese
Sodium
Total Hardness
Lead

Microbiological

Total Coliform

Table 3-2 - continued
City of Salem
ASR Implementation Plan: Water Quality Monitoring Program

Conventional Parameters

Oxygen Reduction Potential (Field Data)
Chloride
Silica
Nitrite (as N)
Total nitrate & nitrite
Sulfate
Nitrate (as N)
Fluoride (free)
Total Alkalinity
Carbonate Alkalinity
Hydroxide Alkalinity
Bicarbonate Alkalinity
Carbon Dioxide
Total Phosphate
Iodide
Total Trihalomethanes

Volatile Organics

Benzene
Bromobenzene
Bromochloromethane
Bromodichloromethane
Bromoform
Bromomethane
n-Butylbenzene
sec-Butylbenzene
tert-Butylbenzene
Carbon tetrachloride
Chlorobenzene
Chloroethane
Chloroform
Chloromethane
2-Chlorotoluene
4-Chlorotoluene
Dibromochloromethane
1,2-Dibromo-3-chloropropane
1,2-Dibromoethane
Dibromomethane
Hexachlorobutadiene
Isopropylbenzene
4-Isopropyltoluene
Methylene chloride
Naphthalene
n-Propylbenzene
Styrene
1,1,1,2-Tetrachloroethane
1,1,2,2-Tetrachloroethane
Tetrachloroethene
Toluene
1,2,3-Trichlorobenzene
1,2,4-Trichlorobenzene
1,1,1-Trichloroethane
1,1,2-Trichloroethane
Trichloroethene
Trichlorofluoromethane
1,2,3-Trichloropropane
1,2,4-Trimethylbenzene
1,3,5-Trimethylbenzene

Table 3-2 - continued
City of Salem
ASR Implementation Plan: Water Quality Monitoring Program

Volatile Organics

1,2-Dichlorobenzene
1,3-Dichlorobenzene
1,4-Dichlorobenzene
Dichlorodifluoromethane
1,1-Dichloroethane
1,2-Dichloroethane
1,1-Dichloroethene
cis-1,2-Dichloroethene
trans-1,2-Dichloroethene
1,2-Dichloropropane
1,3-Dichloropropane
2,2-Dichloropropane
1,1-Dichloropropene
cis-1,3-Dichloropropene
trans-1,3-Dichloropropene
Ethylbenzene
Vinyl chloride
m,p-Xylene
o-Xylene

LONG-TERM HYDROLOGIC MONITORING PROGRAM

During development and operation of the ASR system, hydrologic data are needed to monitor system performance. In this regard it is necessary to monitor groundwater levels in the ASR aquifer. It is also necessary to monitor surface flow rate in specific areas where leakage to surface water may occur. General details for the monitoring program are as follows:

Groundwater Level Monitoring

Groundwater level data will be collected from the ASR aquifer in existing and newly installed wells. The data should be collected using dedicated equipment provided at each of the wells. Measurements should be recorded by the equipment on a frequency at approximately 4 to 8 times daily.

Surface Water Monitoring

Two surface water gaging stations should be identified and used for long-term recording of stream flows. The monitoring points should be located in Pringle Creek, near to the Salem downtown area, and also in Croissan Creek, near to or downstream from River Road. The stream gaging stations should be used to collect stream flow data during the summer months, July and August. During this period, measurements should be collected approximately once per every 4 weeks. Thus, 2 to 3 measurements should be collected from each station during each year.

Is this enough measuring?

Monitoring Plan and Periodic Reporting

I assume this refers to the final project not the testing phase

A monitoring program plan should be prepared to document the long-term monitoring procedures and reporting requirements. The plan should be prepared at the onset of the monitoring program. The plan will clearly identify responsible parties, monitoring locations, data collection methods, data collection frequencies, data storage, and reporting requirements. At a minimum, the data should be technically analyzed once every 3 to 5 years. The technical analysis should evaluate the quality of the data. Specific analyses should be completed to assess ASR system efficiency and the rate of leakage to surface water.

WELLHEAD PROTECTION PROGRAM

Wellhead protection programs are a voluntary regulation in the State of Oregon. Public water systems relying on groundwater may choose to develop a wellhead protection program. Purveyors with a wellhead protection program may have greater opportunity for state funding assistance and may be relieved of certain water quality monitoring requirements. In addition, purveyors with wellhead protection programs will have more control and knowledge regarding vulnerability of groundwater to contamination.

A wellhead protection program should be developed for the ASR system to ensure that land uses and other activities in the area will not jeopardize the aquifer water quality. A summary of the wellhead protection program components is provided below:

Wellhead Advisory Committee

A wellhead advisory committee should be established at the onset of the wellhead protection program. The purpose of the committee is to support the City's wellhead protection program by selecting management activities and subsequently, assisting with implementation. Members of the committee should include a cross section of the community with interest/concern in land use issues (citizen groups, businesses groups, public agencies). City planners, water operations staff, fire department staff, and others that may ultimately be responsible for implementation of management activities should also be committee members. At least one elected official should participate in the committee and concur with the selected management activities.

ASR Aquifer Computer Model

The initial technical component of a wellhead protection program is the delineation of wellhead protection areas. The wellhead protection area is determined based on the time-of-travel for groundwater to reach an ASR well. Typically, these areas are based on travel times of 1-year, 5-years, and 10-years. The wellhead protection areas provide a focus for management activities and other components of the wellhead protection program.

The wellhead protection program should include the development of a numerical computer model. The model should include the entire ASR aquifer. It can be used for delineation of wellhead protection areas for the existing ASR wells at the time the model is developed. It can also be used for delineation of wellhead protection areas for new wells constructed in the future.

The computer model can also be used for assessing ASR system performance for different injection, storage, and withdrawal scenarios. This application is not a wellhead protection requirement but will assist the City in best managing the ASR system. Thus, the computer model developed for wellhead protection will also have use for ASR operations.

Contaminant Source Inventory Database

The contaminant source inventory consists of identifying all of the potential and existing sources of contamination that could affect groundwater quality. The wellhead protection program should include development and long-term upkeep of a contaminant source inventory database.

The inventory is completed by first searching records collected at the local, state, and federal levels. A field survey is then completed to verify the accuracy of the records search. The verified source inventory is then documented in a computer database. The source inventory is periodically updated and revised, approximately every 2 to 5 years. The principal use of the source inventory in wellhead protection is simply to document the potential sources that exist above the ASR aquifer. The initial inventory, however, can also be used to assess the most important sources, thus, providing a focus for identifying groundwater management activities.

Spill Response Planning

Spill response planning related to wellhead protection involves coordination with local spill response teams. These teams, often called HAZMAT teams, are common to local fire departments. They respond to spills which occur at facilities and along transportation corridors. With regard to wellhead protection, spill response planning primarily involves educating the HAZMAT team about the aquifer and ASR well locations. It is also typically necessary to establish a communication chain whereby ASR operations staff would be notified when spills occur in the area of the ASR aquifer.

Contingency Planning

Contingency planning in wellhead protection focuses on loss of water supply due to a contamination event. Contamination scenarios are developed for the ASR wells and appropriate response procedures are documented that can be used during an emergency.

Management Activities and Implementation

The ultimate success of a wellhead protection program depends on the management activities that are identified and implemented. The wellhead protection program should consider an array of possible activities. The activities should focus on the areas in which the ASR aquifer is considered most vulnerable. The wellhead advisory committee should make final recommendations for management activities. Following the final recommendations, detailed implementation and funding plans should be prepared for each recommendation. These plans will provide the structure for implementation of the recommendations.

ASR SYSTEM DATABASE

Data collected on an on-going basis for the ASR system includes water quality, pumping/injection volumes, groundwater levels, and stream flow rates. These data will be used for reporting and analysis at various times during operation of the ASR system. The data may also have use in trouble shooting unforeseen problems which arise in the future. For these purposes, the ASR system should include a sophisticated database and data management plan. At the onset of database development, a data management plan should be prepared documenting the organizational structure and uses of the data, data entry and reporting, and backup procedures.

SYSTEM OPERATION REQUIREMENTS

In order to ensure that the ASR water supply system maintains developed levels of capacity, well performance testing needs to be completed on each of the ASR wells. Well performance testing will indicate the need for well rehabilitation, which will be necessary periodically.

Well Performance Testing

Injection through ASR wells will result in deposition of particles in the aquifer adjacent to the borehole. These particles can reduce the hydraulic connection between the well and aquifer. Other processes may also be active that have the same effect, such as biological growth in the well and mineral precipitation. The well efficiency will decline due to deposition of materials in the well borehole.

The ASR system operations should include periodic well performance testing to assess if well performance has deteriorated. The initial performance test conducted at the time the well was constructed can be used for comparison. The well performance testing should consist of a step pumping test with four sequential pumping rates. Water levels in the well should be monitored throughout the test (e.g., at 60 second intervals). Declines in performance greater than 10% should be treated by rehabilitation of the well. In the initial years of the ASR system (through Year 5), well performance declines and the ability to rehabilitate wells should be carefully monitored. After several years of experience, regular schedules for performance testing and rehabilitation can be developed.

Well Rehabilitation

In the initial 5 years of operating the ASR system, well rehabilitation should be conducted for well efficiency declines greater than 10% (as compared to the efficiency when the well was new). Rehabilitation efforts should begin by using the existing pumping equipment in the well to create a surging action. A sequence of injection and pumping should be used to dislodge the materials causing the reduced efficiency (for example: injection 2 minutes, pumping 2 minutes, repeated several times). Rehabilitation by this method should be continued until little or no material is removed from the well when the pump is first turned on. At the end of the rehabilitation effort, a well performance test should be conducted.

If it is found that well performance has declined and cannot be rehabilitated using the existing pumping equipment, a more rigorous rehabilitation program should be pursued. This program would begin with sampling and video of the well borehole. The ensuing rehabilitation strategy may include the use of specialized equipment to surge and jet the borehole and also the use of chemicals.

PERMITTING REQUIREMENTS

Year 1 and Year 2 of the ASR Water Supply project required the application for water rights permit. The proposed Year 3 and Year 5 ASR wells will also require application for water rights permit. Unlike the permitting process encountered for Year 1 and Year 2 development of ASR Well No. 1, future permitting should be less encumbered with newly adopted State legislature. Permitting for the remaining ASR water supply project will be groundbreaking in the sense that the City of Salem ASR project will be a test case for the Oregon Water Resources Department's new ASR Statutes. The permitting requirements for the Year 3 and Year 5 ASR wells are discussed in the following paragraphs.

Background

The regulatory permitting requirements for the City of Salem's ASR project have been complex and evolving. The operation of the pilot study in 1995 and the operation of ASR well No. 1 in 1996, is covered under three water rights permits. One permit temporarily transfers 2.5 cfs of the City's 22 cfs 1923 water right on the North Santiam River (Certificate 12033) from municipal use to groundwater recharge use for the ASR pilot program. A second permit authorizes the storage of that water in the ground. The third permit authorizes removing the water from the ground and applying it for municipal use. These rights will expire in April 1997 and the City's full 22 cfs water right on the North Santiam for municipal purposes will be restored.

In 1995, the Oregon Legislature modified the water rights process for ASR systems (see ORS 536.027, and ORS 537.531 - 537.534). The Oregon Water Resources Department (OWRD) developed rules which were adopted in early 1996, implementing the new ASR statutes. These rules are found in OAR 690-350-010 through OAR 690-350-030.

For the purposes of the new permit system, ASR is defined as "...the storage of water from a separate source that meets drinking water standards in a suitable aquifer for later recovery and not having as one of its primary purposes the restoration of the aquifer." While an applicant still can go through the process of permitting an ASR project using the system in place prior to 1995 (the system used to permit the pilot study), the new permit process offers several advantages to the City.

No distinction was made in the pre-1995 permitting process between project development and testing and full scale implementation. The number and type of permits, and the public interest criteria which must be met for approval, are the same in both cases. Threshold information needed for approval of the full system is not available until after some testing has occurred. The new system allows the City to obtain a Limited License for up to five years in order to demonstrate the efficacy of the ASR system. This license can be renewed if additional testing is required. Once full testing is completed, then a permanent ~~application and certificate~~ permit can be obtained based upon the results of the Limited License testing program.

The pre-1995 legislation did not recognize ASR as a municipal use of water. Therefore, Salem either had to apply for additional water rights on the North Santiam River for the purpose of aquifer storage, or transfer some of its existing municipal-use rights to aquifer storage rights. It is highly unlikely that new water rights could be obtained for such purposes. While it was acceptable to temporarily transfer the use of some of the City's existing water rights for the pilot test program, transferring water rights permanently would not be desirable, as it would diminish the City's available long-term supply.

The new legislation recognizes ASR as a beneficial use inherent in all water rights for other beneficial uses. Use of water as an injection source for an ASR project does not affect the existing source water right in any way.

In addition to the water rights permit, the pre-1995 permit system also requires a State Water Pollution Control Facilities (WPCF) permit from the Oregon Department of Environmental Quality (ODEQ). This permit requires compliance with the State's non-degradation policy for groundwater. It is difficult to argue "non-degradation" of the aquifer, however, as the different amounts of minerals or other substances (e.g., fluoride added to the treated water) found in the injected drinking water can exceed the amounts present in the native groundwater at the site of injection, and therefore can be considered as a degradation. For the purposes of the pilot test study, ODEQ agreed to a Memorandum of Understanding with the City that provided for specific water quality monitoring and reporting on a series of wells for a large number of parameters and potential contaminants, in lieu of the WPCF permit. However, such a WPCF permit would be required for a permanent ASR system under the pre-1995 system.

The new permit system exempts an ASR system from the WPCF permit requirement if the injected water meets drinking water standards established by the Oregon Health Division (OHD) or groundwater standards established by ODEQ, whichever is more stringent. If regulated constituents are found at levels greater than 50% of the established levels, the ASR license or permit may require the permittee to employ "...technically feasible, practical, and cost-effective methods..." to minimize the amounts of these constituents. Because the City's North Santiam source meets drinking water standards, the source is eligible for the exemption from the WPCF permit under the new permit system.

Limited License Application

As a consequence of the advantages of the new permit system, a permit application for a Limited License has been prepared and submitted to OWRD. This application, ASR LL-1, is the first such application under the new permit system. The application covers the storage of up to 1.0 billion gallons of water and a withdrawal rate of up to 20 mgd.

In 1997, up to 350 MG could be stored, increasing to 700 MG in 1998 and reaching the 1.0 billion gallon level in 1999. Withdrawal could occur at the rate of up to 11.5 mgd in 1997 and reach 20 mgd in 1999. Up to 15 wells would be constructed by the summer of 1999 (including the already constructed ASR Well No. 1 and ASR Well No. 2) under the Limited License. The duration of the application is 5 years.

The application is currently pending with OWRD. Based on initial feedback from OWRD, it is anticipated that the Limited License will be obtained sometime in late summer or early fall of 1996. It should be noted that prior to securing a Limited License for all ASR wells including ASR Well No. 1, the existing OWRD permit, application 75207, will continue to be used by the City for use in the injection and extraction of water as specified in the application.

Once the City receives the Limited License, it will be able to operate under its terms for the next five years. The City will be able to inject and withdraw in accordance with the application. It is anticipated that the License will require an ongoing program to monitor water quality, water levels in the aquifer, the potential impacts on an area of landslides in South Salem, and on flows in selected streams and creeks in South Salem.

The application also requires specifying exactly where each well which is contemplated under the Limited License shall be located. Because it is impossible to know at this point exactly where some of these wells will go, both from the perspective of property acquisition and from the perspective of the geological and aquifer conditions which will be encountered, it is likely that the City will need to modify the License during the course of the 5 year period the License is in effect to adjust well site locations. This will require a formal application and review process, which should not prove difficult to accomplish.

Permanent ASR Water Rights

Under the new permit process, the City can apply for a permanent water right for the ASR system only after the completion of the ASR program under the terms of the Limited License. Assuming the Limited License permit is issued in 1996, the City will need to apply for permanent ASR rights in 2001. This application will be based on the results and findings of the Limited License program. The permanent water right will contain conditions on the injection rate, storage amount, recovery rate and the monitoring program for water quality, quantity, and other issues. OWRD must find that the application is in the public interest. Protests to the OWRD decision can be made by any party, with subsequent referral to a contested case hearing or to the Water Resource Commission.

There is, of course, no guarantee at this time that the permanent water right application will be granted. Presuming that the results of the Limited License program parallel the results which were obtained in the pilot test program, there should be little risk of not obtaining a permanent water right. However, even under these circumstances, approval cannot be made certain at this time. The City must recognize that there is some risk that its investment in the ASR Limited License program will not prove fully useable once a permanent application is made.

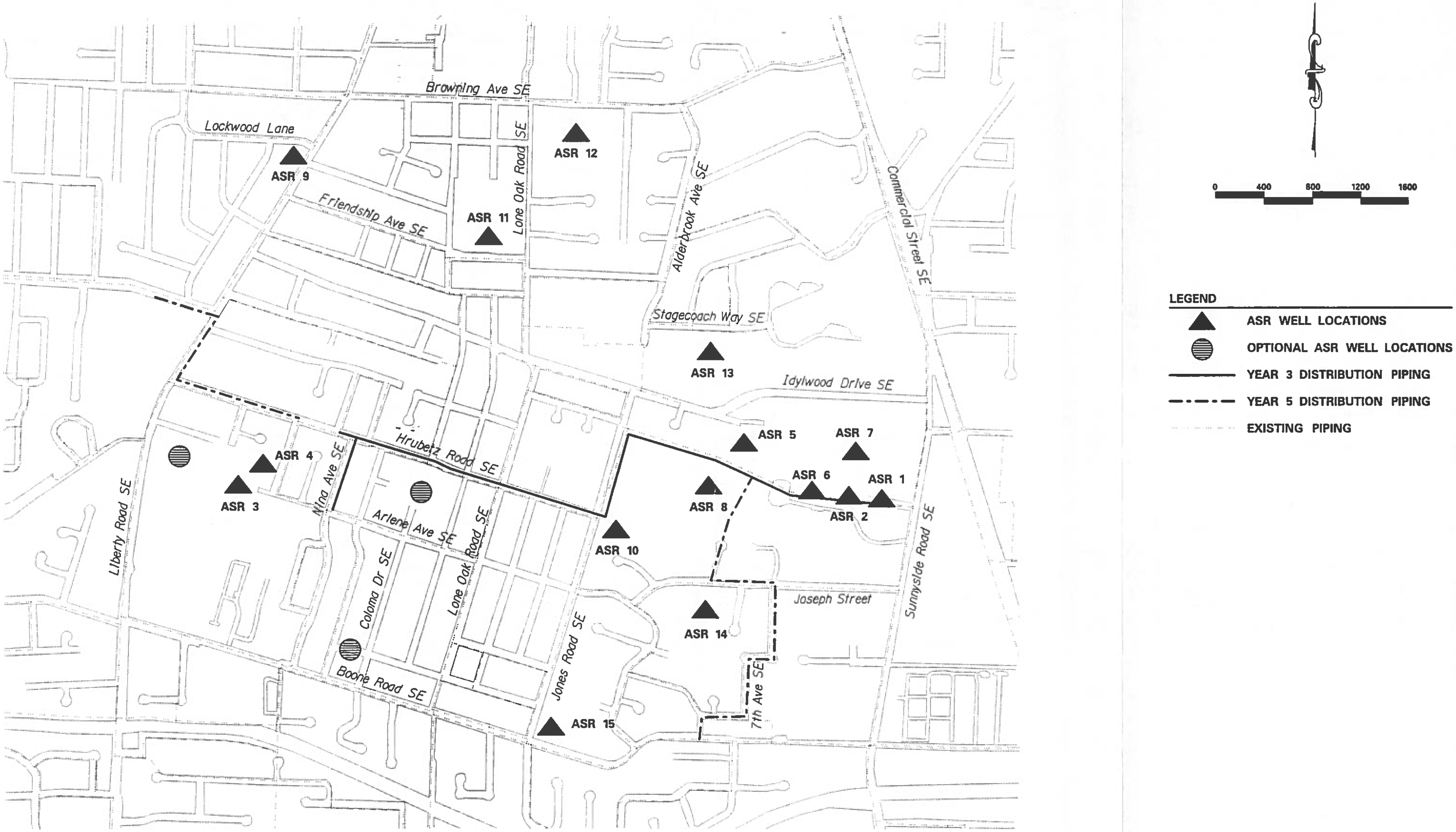
An alternative to the use of the new permit process which might not carry a risk of some unusable investment, would be to use the pre-1995 permit approach. Permanent water rights would be applied for in a similar fashion to those for the 1995 pilot test. Because, as stated earlier, it is highly unlikely that new water rights for withdrawal of North Santiam water could be obtained, the City would have to be willing to reduce the availability of its long-term water supply rights through a transfer of some of its existing water rights to ASR. Even if the City was willing to accept this reduction in long-term water rights, the pace at which it could develop the ASR system would likely be much slower than currently planned. Given the response to the initial application for a Limited License by OWRD, they would be highly unlikely to provide permanent rights for the full ASR system based on current information. Instead, the City would have to apply incrementally for development of the system, to prove the system works each step of the way. This approach would take longer and be more costly than the Limited License approach.

Given these alternatives, the permanent application based upon a Limited License is the recommended approach for implementation of the ASR system. To minimize the risk of OWRD failing to approve the permanent application, a phased development program developed in conjunction with OWRD, ongoing monitoring, ongoing contact with OWRD, and ongoing contact with key outside interest groups who could protest a permanent application, are all recommended elements of the implementation program for permitting the ASR system.

Waste Water Discharge Requirements

Discharge of wastewater extracted from individual ASR wells prior to conveyance into the distribution system will occur during specific operating events such as initial startup and well rehabilitation. Depending upon the ASR well site, discharge may be directed to a storm drain for convenience. This is the physical arrangement which exists for ASR Wells No. 1 and No. 2. In these instances, a discharge permit may be required from ODEQ. Since the discharge is infrequent and generally of short duration, and the water is uncontaminated groundwater and injected surface water, the potential impacts are minimal.

If a discharge permit is required, the water quality requirements have been specific to pH (range 6-9) and minimal chlorine residual ($\leq$ 0.011 mg/l). Both of these conditions should be met from each well site particularly after aquifer storage periods. It is recommended that once the specific discharge location of wastewater from each well is identified, a discharge permit requirement be reviewed with ODEQ.



Base mapping provided by the City of Salem.

ASR Water Supply Facilities
Figure 4-1

MONTGOMERY WATSON

Section 4
Implementation Requirements

The City of Salem *Water System Master Plan* indicates that the maximum day water demand exceeds current available supply capacity. The City of Salem initiated the ASR project to meet current and projected water demands for summer peak periods and under emergency operating conditions. The program was developed with a 5 year implementation schedule. Currently, the ASR project is at the close of the second year, with Year 3 beginning in July 1996. Year 5, which is the final year of the project, ends in July 1999. The following paragraphs of this section describe the implementation requirements for Years 3 through 5 in obtaining objectives of the ASR program.

WATER SUPPLY NEEDS

The goal of the ASR project is to provide a minimum of 10 mgd supply capacity and 350 mg storage capacity by the summer of 1997. Further, another 10 mgd supply capacity, and an additional 650 mg of storage would be available through the ASR project by summer 1999. In total over the five year implementation period 20 mgd supply capacity and 1.0 billion gallons storage capacity would be available for the City.

As discussed in previous sections of this report, wells ASR Well No. 1 and ASR Well No. 2 have been drilled, tested, and ASR Well No. 1 put into operation during the first two years of the project. ASR Well No. 2 is expected to be operational during the summer of 1996. The combined supply capacity for ASR Well No. 1 and ASR Well No. 2 totals 2800 gpm or 4.0 mgd. A minimum of an additional 4200 gpm, (6.0 mgd) is needed to meet the desired 10 mgd supply capacity goal by the end of Year 3. However, in order to maintain reserve supply capacity the City has elected to develop the Year 3 capacity to 10 mgd with one well out of service. This brings the desired capacity for the Year 3 plan to a total of 8000 gpm (11.5 mgd), which leaves development of an additional 5800 gpm (8.5 mgd) in Year 5 to meet the total desired 20 mgd goal. The supply capabilities and storage volumes described herein are consistent with the requests submitted to OWRD in the Limited License permit application.

SUMMARY OF PROPOSED WATER SUPPLY FACILITIES

The proposed facilities for the ASR project include the ASR wells, distribution system improvements, and pressure reducing stations. The ASR wells include the well and a masonry block building, which houses the well pump, pump instrumentation and control, and sodium hypochlorite disinfection system. The distribution system improvements consist of transmission piping necessary for moving water from the ASR well sites to areas where the water demands are higher and to other pressure zones. The pressure reducing stations will connect the higher S-2 pressure zone with the G-0 and S-1 pressure zones. The following paragraphs discuss these facilities in greater detail.

ASR Well Design Location and Withdrawal

Selection of well sites and anticipated water withdrawal rates are based on two factors: 1) presumed availability of property for development, and 2) results of the ASR pilot work. Nearing the start of Year 3 and desiring to have a nominal total withdrawal capacity of 10 mgd available at the end of Year 3, City owned properties were identified for Year 3 well sites. This requirement for City-owned property was desirous to facilitate implementation and eliminate the need for timely property acquisition. Results of the hydrologic analysis have identified the anticipated withdrawal rates for the different areas within the Salem Heights aquifer, and correlating these with available properties for well development the number and anticipated well withdrawal for the Year 3 plan has been identified.

Six wells ranging in anticipated withdrawal rates of 600 gpm to 1000 gpm have been identified for construction in Year 3. These six wells in combination with ASR-1 and ASR-2 would bring the total Year 3 capacity up to 8000 gpm or 11.5 mgd. The additional capacity beyond 10 mgd allows one well to be out-of-service, while maintaining a 10 mgd supply capacity.

The Year 5 plan increases ASR supply capacity from the nominal 10 mgd to 20 mgd by July 1999. Seven ASR wells ranging in capacity from 600 gpm to 1000 gpm have been identified for Year 5 development. The total anticipated capacity of these wells is 5800 gpm or 8.4 mgd. Total ASR capacity at the end of the Year 5 planning period would be 20 mgd.

The well locations have been identified on Figure 4-1. The anticipated withdrawal rate, location, and apparent property ownership for the Year 3 and Year 5 ASR wells is summarized in Table 4-1.

Table 4-1
ASR Water Supply Well Summary

ASR Well ID	Well Site[a] No.	Capacity (gpm)	Proposed Well Diameter (inches)	Apparent Property Ownership	Status
ASR Well No. 1	N/A	1000	12	City	In-service
ASR Well No. 2	N/A	1800	16	City	Construction Complete
ASR Well No. 3	1	600	12	City	Year 3
ASR Well No. 4	2	600	12	City	Year 3
ASR Well No. 5	3	1000	12	City	Year 3
ASR Well No. 6	4	1000	16	City	Year 3
ASR Well No. 7	5	1000	16	City	Year 3
ASR Well No. 8	6	1000	16	City	Year 3
ASR Well No. 9	7	1000	12	Private	Year 5
ASR Well No. 10	8	1000	12	School	Year 5
ASR Well No. 11	9	600	12	School/Private	Year 5
ASR Well No. 12	10	600	12	School	Year 5
ASR Well No. 13	11	1000	12	Private	Year 5
ASR Well No. 14	12	1000	12	Private	Year 5
ASR Well No. 15	13	600	12	Private	Year 5

(a) Previous communications related to property acquisition reference well site nos.

The withdrawal capacities shown in Table 4-1 are estimates based on the hydrologic data collected during Years 1 and 2 of the ASR project. The withdrawal capacities are considered conservative and may actually be greater than those shown. If that is the case it may be possible to eliminate one or more of the wells shown for development. In the event that a well capacity is less than anticipated, it may be desirable to develop one of the optional well sites.

Based upon the current hydrogeological knowledge of the aquifer. Sizing of individual wells has been determined and is shown in Table 4-1. Note that the proposed sizing for ASR Well No. 6, ASR Well No. 7, and ASR Well No. 8 is 16-inch diameter and is based upon the predicted capacity which might be obtained at this location. Actual capacity will be determined during testing of the well following drilling. If a higher capacity is obtained, it may be possible to delete a smaller well to achieve the total system capacity. The well sizes indicated in Table 4-1 have been used to estimate project costs discussed in later paragraphs of this Section.

The optional well sites are also shown on Figure 4-1. Development of the optional well sites may be necessary, because of unsuccessful land/easement acquisition for any of the Well Site Nos. 1 through 13. The apparent ownership of the optional well sites is private, and the anticipated well capacity at each of the optional well sites is estimated at 600 gpm.

The 15 ASR wells shown in Table 4-1 are generally located within residential areas. ASR Well Nos. 1, 2, 3, 5, 6, 7, and 8 are all located within Woodmansee Park. As noted ASR Well No. 1 and ASR Well No. 2 are complete and will share a common well house and disinfection facilities. It is assumed that all remaining well sites will have a configuration identical to ASR Well No. 1 which includes a room for pump/piping equipment and a separate room for disinfection equipment.

As noted, it has also been assumed that each well site will duplicate the materials of construction used for ASR Well No. 1 and ASR Well No. 2. It may be determined during future property negotiations that this architecture is not acceptable for certain locations. These impacts should be incorporated and reflected in any cost revisions for construction of the facilities.

Access to each ASR site would be provided across the easement to allow operation and maintenance activities. Consistent with system requirements, each ASR site will be provided with SCADA equipment which includes local controllers, radio telemetry and remote monitoring and control. Visible SCADA facilities at each site will include pole type radio antennae.

Each ASR site will be provided with connection piping to the nearest distribution system pipe. An estimate of pipe requirement has been provided for each site and included in the project cost estimate. An 8-inch pipe was assumed for 600 gpm well sites and 10-inch minimum for all other sites.

Each ASR well will require a pump to waste pipe for discharge of water that is not introduced into the distribution system. These facilities are expected to be used infrequently during startup and rehabilitation periods. An inventory of acceptable disposal locations should be performed during the design and implementation of each well facility. The nearest storm drain or sanitary sewer would be viable discharge locations, but would require an air gap between the ASR discharge and drain connection. It has been assumed that each well will have a waste discharge to a sanitary sewer for facility estimating purposes. Discharges to storm drains which ultimately reach a surface drainage may require a discharge permit from ODEQ. The discharge requirements have identified a water quality with a specific pH range and essentially no chlorine residual. These conditions are likely met with not treatment being necessary prior to discharge.

During construction of ASR Well No. 1, some delay in completion of the facility was caused by time required to provide adequate 480 volt power supply to the site. This situation was partially aggravated by new construction along Sunnyside Road, however, scheduling of power distribution modifications were noted to require significant lead time. A preliminary reconnaissance of power supply was not performed with PGE during preparation of this report.

Identification of available electrical power and coordination with PGE at each of the wells sites is recommended as an immediate task to ensure the timely completion of the ASR well development. An estimate of power supply development has been prepared for each site conservatively assuming that extension of service will be required at each site.

Water Treatment

Analysis of background water quality within the aquifer (MW) indicates that it compares similarly in concentration by characteristic to the surface water supply that is used for injection. The background water quality data (MW) also has not indicated any contamination from surface or subsurface sources. Therefore, treatment of the potable water being injected into the aquifer is not required nor is the groundwater.

Discussions were conducted with OHD relative to other potential treatment requirements relative to water that is withdrawn from storage and directed into the distribution system. It has been determined by OHD that extracted water from ASR storage should be disinfected prior to entering the distribution system and match the disinfection residual present in the system. Since chlorine is used for disinfection, it will be necessary to provide chlorination at each ASR site.

Hypochlorite storage and chemical feed equipment will be needed at each ASR site. These disinfection facilities will be similar to that provided for ASR Well No. 1 and ASR Well No. 2. The chemical feeders are designed to feed a range of 0-1.0 mg/l chlorine as sodium hypochlorite. The dosage is manually set and the feeder is automatically paced by the ASR discharge flow meter. Normal dosage will be to provide a 0.5 mg/l residual to meet system conditions. In addition to flow pacing, the City has requested that chlorine residual analyzers be provided for additional control and monitoring primarily to reduce the potential of chemical overfeeding.

The current drinking water regulations for groundwater as interpreted by OHD do not require that a specific "CT" (disinfectant concentration - C, and contact time - T) be provided for achieving various levels of microbial inactivation. CT is satisfied in the surface water supply prior to injection and microbial contaminants have not been identified in the groundwater. It is not known whether the Groundwater Disinfection Rule will require meeting CT for extracted groundwater and these aspects of the rule are not expected to become mandated for several years. If CT is required by rule changes, effectively increased contact time will be needed between the point of disinfection addition and the first point of consumption. It is recommended that the development of these rules be monitored and the impacts of CT, if required, be evaluated for feasibility and implementation at each ASR site. It would be easier to implement CT storage in the vicinity of a cluster of ASR wells such as will be located in Woodmansee Park as opposed to individual sites. These issues would be reviewed, if required, when rule changes are promulgated.

Distribution System Improvements

During the hydraulic modeling process described in Section 3, it was determined that additional distribution pipelines would be needed to augment the flow of water from the ASR system. Results of the hydraulic model analysis indicate that an east/west connection extending from the Woodmansee Park ASR wells to the existing 12" diameter distribution piping at Arlene Avenue SE and Nina Avenue SE and at Hrubetz Road SE and 2nd Place. The hydraulic modeling analysis results indicate that a 16" diameter pipeline would be required to meet future water demands and distribution requirements within the S-2 pressure zone. Based on the proposed alignments approximately 5070 feet of 16" diameter and 800 feet of 12" diameter pipeline would be needed to augment to flow of ASR supply water from the east to the west of the S-2 service area. In addition to the moving ASR water east/west, it is also desirable to augment the flow of water to the southern portion of S-2 where the bulk of future growth will occur. Major flow distribution is also required to the Boone Road pump station location in meeting both future peaking and emergency demand conditions. Strengthening the ability to move ASR supply from the S-2 pressure zone to the south and east of Woodmansee Park will be a beneficial improvement.

A north/south pipeline connection from the Woodmansee Park ASR wells to the existing 16" diameter pipeline in Boone Road would enhance the flow of ASR water from the north of S-2 to the southern portions of the S-2 service area. Approximately 2700 feet of pipeline would be required to make this connection. Preliminary pipeline routing for the east/west and north/south connections within the S-2 service area are shown on Figure 4-1. Actual pipeline routes may vary from those shown, however for planning purposes and establishing a pipeline length these routes are considered reasonable.

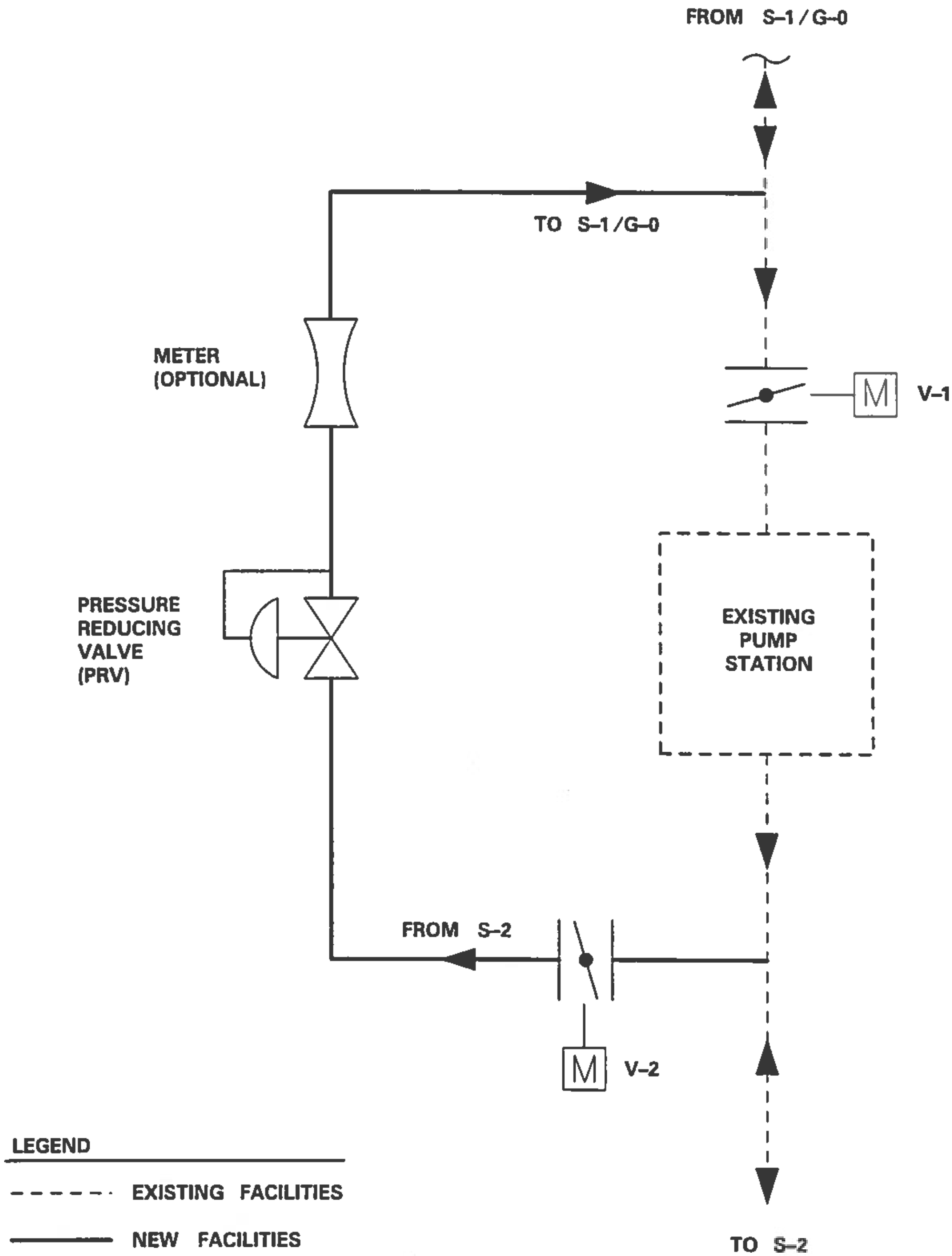
Further providing an emergency intertie between the S-2 and S-3 pressure zones has been determined to be desirable for increasing source of supply reliability. An intertie between the S-2 and S-3 pressure zones can be made with a direct connection between ASR Well Nos. 3 and 4 with the S-3 pressure zone 12" diameter pipeline located in Cunningham Lane S. The distance from the Arlene Park location which would contain ASR Well No. 3 and ASR Well No. 4 facilities and extending to the existing S-3 pipeline is approximately 3500 feet. A 12" diameter pipeline would be required to keep the velocities of the potential 1200 gpm flow from ASR Well No. 3 and ASR Well No. 4 to less than 4 feet per second.

Pressure Reducing Stations

Pressure reducing stations which bypass the Fairmont, Boone, and Edwards booster pump stations are desirable for providing an emergency intertie between the S-2 ASR water supply and the lower S-1 and G-0 pressure zones and also to distribute peak supply in excess of S-2 demands and within the delivery capacity of the ASR system. The pressure reducing stations at the Edwards and Boone booster pump stations would allow water to flow by gravity to the G-0 pressure zone, by providing a path around the existing pumps. Similarly, the pressure reducing station at the Fairmont pump station would allow water to flow from the S-2 ASR supply to the S-1 service area. Pressure reducing valves are needed at each of these bypasses to lower the hydraulic gradeline of the water coming from the S-2 pressure zone such that it meets the hydraulic gradeline of the lower pressure zones.

Figure 4-2 presents a simplified schematic of a typical pressure reducing station. It is assumed that the existing booster pumps have a check valve which prevents the flow of water to reverse through the pumps. Under normal operating conditions water would be pumped from the lower G-0 or S-1 pressure zones into the higher S-2 pressure zone to meet service area water demands or for storage in the ASR system. In the pumped water condition, the motor operated valve (V-1) upstream of the pump station would be open and the motor operated valve (V-2) on the by-pass line closed. Under emergency or peak supply conditions when water is needed in the lower pressure zones, the valve on the by-pass pipeline would open and the valve upstream of the booster pump station would close. A water meter is shown on Figure 4-2 for measuring the flow of water from S-2 to the lower pressure zones. This would provide the City with a means to quantify the availability of excess flow from the ASR system.

It has been assumed that the pressure reducing valve, motorized valve (V-2) and meter (optional) would be housed in a below ground vault. Motorized valve (V-1) would be located underground unless it could be economically accommodated within the pump station. The motorized valves and meter output would be connected to the City SCADA system. Programmable logic would be provided to automatically open and close the motorized valves based on specific system conditions



Schematic
Typical Pressure Reducing Stations
Figure 4-2

such as loss of pressure within lower pressure zones. It is further assumed that the control logic would lockout the booster pumps from operation during flow through the PRV valves.

OTHER FACILITIES AND ACTIVITIES

In order to complete the proposed water supply facilities and provide the City with monitoring tools there are additional elements that are necessary in the implementation of the ASR project. These other elements include property/easement acquisition for those wells not located on City property, the installation of the groundwater level monitoring wells, and a decision flow chart for determining the applicability of particular well development as the project progresses through construction.

Easements and Property Acquisition

The ASR well locations identified on Figure 3-1 and 4-1 consist of privately owned, City owned, and institutional property sites. The Year 3 ASR wells have all been located on City owned property to ensure that property/easement acquisition does not hinder the development of the wells by the end of the Year 3 plan. The sites identified for Year 5 development are all either privately owned or school properties. In either case the Year 5 well sites will either need to be acquired or a permanent easement negotiated with the owner. The actual parcel size and the ability to short-plat the parcel will in part determine the dollars required for acquisition. Where the City desires to purchase an easement, such as with institutional properties, the area required for the easement would in part be determined by minimum set-back requirements as required by Oregon Health Division (OHD) for well placement.

Maintaining a 50 feet radius (ODH requirement) around the well for the zone of influence would require that a minimum of 10,000 square feet of property be acquired for each ASR well. In addition an easement for access would be required. Properties identified for well sites 7 (ASR Well No. 9), 11 (ASR Well No. 13), and 12 (ASR Well No. 14) are in excess of an acre and may warrant short-platting. The feasibility of acquiring partial parcels would need to be investigated by the City's property division. Further, the proposed well site 11 is on a long narrow parcel adjacent to a church which maintains access adjacent and to the rear of desired well site 11. In this case the access to the well site may be negotiated with the church while, the actual well location is on adjacent property. Again, this is an element of easement/property acquisition which the City's property division may wish to investigate.

Well site No. 13 (ASR Well No. 15) is identified for location on a parcel which is less than 10,000 square feet, requiring a possible variance from the Oregon Department of Health prior to development. Once existing utilities are located and property boundaries identified, the need for a variance from set-back requirements should be fully evaluated for all well locations, whether on City, private or institutional properties. Well Site No. 8 (ASR Well No. 10), well site No. 9 (ASR Well No. 11) and well site No. 10 (ASR Well No. 12) are all located on institutional owned properties. Well site No. 8 and well site No. 10 are located on public school properties, both with adequate space for discrete location of ASR well facilities. Well site No. 9 is maintained by the Queen of Peace Church and School, and while a smaller parcel than well sites No. 8 and 10, appears to have adequate area for locating an ASR well.

The environment for property acquisition is unknown and can at times require lengthy negotiation periods. Because of the uncertainty associated with property/easement acquisition, it is recommended that the City start this process immediately to ensure that the Year 5 ASR wells are in place to receive water by April 1, 1999. This date would allow adequate time for injection of Year 5 storage volume prior to a potential peak demand from storage in July. The cost for acquiring property and easements is also uncertain without the benefit of a fair market value analysis.

However, based on preliminary values provided by the City's properties department, residential property within the ASR system would be approximately $3.00 to $4.00 per square foot, and easements on institutional properties approximately $2.00 per square foot. These estimates form the basis for the easements provided in the ASR implementation costs, and are shown as Year 4 costs.

Three optional well sites have been identified as part of the ASR water supply project. The optimal well site locations include one adjacent to the existing Cannery Well, the City right-of-way at the west end of Lori Avenue SE, and one on a church owned property south of Hrubetz Road SE between Firdell Drive SE and Pullman Avenue SE. Each of the optional well sites is estimated to have a potential capacity of 600 gpm. It is recommended that easement/property acquisition for these optional well sites is completed concurrently with the other ASR well locations.

Monitoring Wells

Monitoring wells are required for tracking the impacts of the ASR system on the groundwater levels within the aquifer and to monitor aquifer pore pressure within the landslide area. Monitoring of pore pressure buildup in the landslide area is critical to ensure that the ASR injection does not result in future landslides. Existing out-of-service wells may be utilized for monitoring groundwater levels within the aquifer. A brief discussion on each type of these monitoring wells follows.

Landslide Monitoring Wells

Additional monitoring wells are recommended for groundwater level monitoring in the landslide deposits to supplement the one well installed during Year 2 work. Five additional wells should be installed during development of the full scale ASR system during Year 3 of the program. Each well should be located in the available right-of-way. The wells should be built from 2-inch PVC casing with a slotted screen set immediately above the base of the landslides. The depth of the landslide deposits will range from approximately 50 to 100 feet below ground surface.

Reconstructed Monitoring Wells

Existing wells are present that extend into the ASR aquifer and allow shallow groundwater to cascade down the well borehole. It is known that the Arlene, Cannery, and Friendship Wells are in this condition. These wells should be completed as monitoring wells for use in long-term monitoring. The monitoring well completions will prevent vertical groundwater flow in the boreholes. Reconstruction of these wells would be similar to the work performed for Park wells No. 1 and 2.

Long-Term Hydrologic Monitoring

Long-term hydrologic monitoring will include collection of groundwater-level and stream-flow data. These data will be reported periodically. The long-term monitoring program should be initiated with a monitoring plan. This plan will document responsibilities, monitoring locations, data collection, and reporting. Groundwater-level data can be accumulated automatically with recording pressure level sensor devices identical to that provided in wells during Year 1 and 2 work. Sensor data is downloaded at the site monthly. Streamflow data would utilize existing gages where available and installation of new equipment where not.

It is recommended that all monitoring wells be equipped with pressure level recorders and the City download the data monthly. Data would be reviewed relative to historical levels and status of ASR storage and operation. Unusual aquifer level increases or decreases should be noted and input solicited from the project hydrogeologist during years 3 through 5 of the program and from a qualified hydrogeologist in years following completion of the program.

Stream level data should be collected, on the recommended frequency outlined in Section 3, by City staff and recorded. Identical evaluation as that described for the monitoring well levels should be performed.

Wellhead Protection Program

A wellhead protection program should be completed for the ASR system. The wellhead protection program should include essential components including: wellhead advisory committee; computer modeling and delineation; source inventory; spill response planning; contingency planning; and management planning. Development of a wellhead protection plan is recommended for implementation in Year 3 work.

ASR System Database

Data collected during operation of the ASR system requires a database for storage and retrieval. A database management plan is recommended for future data collection. It is assumed that all data will be incorporated into Microsoft ACCESS, Version 2.0 or later.. The initial product should include a data management plan, a relational database with entry and reporting forms, and training of water system staff with operation of the database. The existing data collected for the pilot test and during Year 2 should be entered into the database. Development of a database system is recommended in Year 3 work. The database would include all well aquifer level data, water available in storage and individual well injection and extraction volumes.

Decision Flowchart

The withdrawal capacity of the Year 3 and Year 5 ASR wells is an estimate, based on the hydrogeologic data collected during Year 1 of the ASR water supply project and the actual well test capacity of ASR Well No. 1. During the development of the Year 3 and Year 5 ASR wells it may be found that the anticipated capacity at each well site is less than the actual capacity obtained following well construction and pump testing, thus reducing the total additional capacity required to meet the 20 mgd withdrawal goal. Conversely, greater capacity may be realized at individual sites following well construction and testing than the assumed capacity shown in Table 4-1. A means to reevaluate ASR well capacity requirements is necessary to balance the number of wells required to meet the goals of this project. A decision flowchart is provided in Figure 4-3 which provides a means for accounting ASR well capacity and the need for well development.

The decision flowchart provides a check for updating capacity requirements and determining future well development needs. The decision flowchart logic also provides a decision path for accommodating ASR wells which may have actual withdrawal rates greater or less than anticipated capacity. The logic of the flowchart should be reviewed following the development of each ASR well. This provides the City with a continuously updated capacity requirements tool.

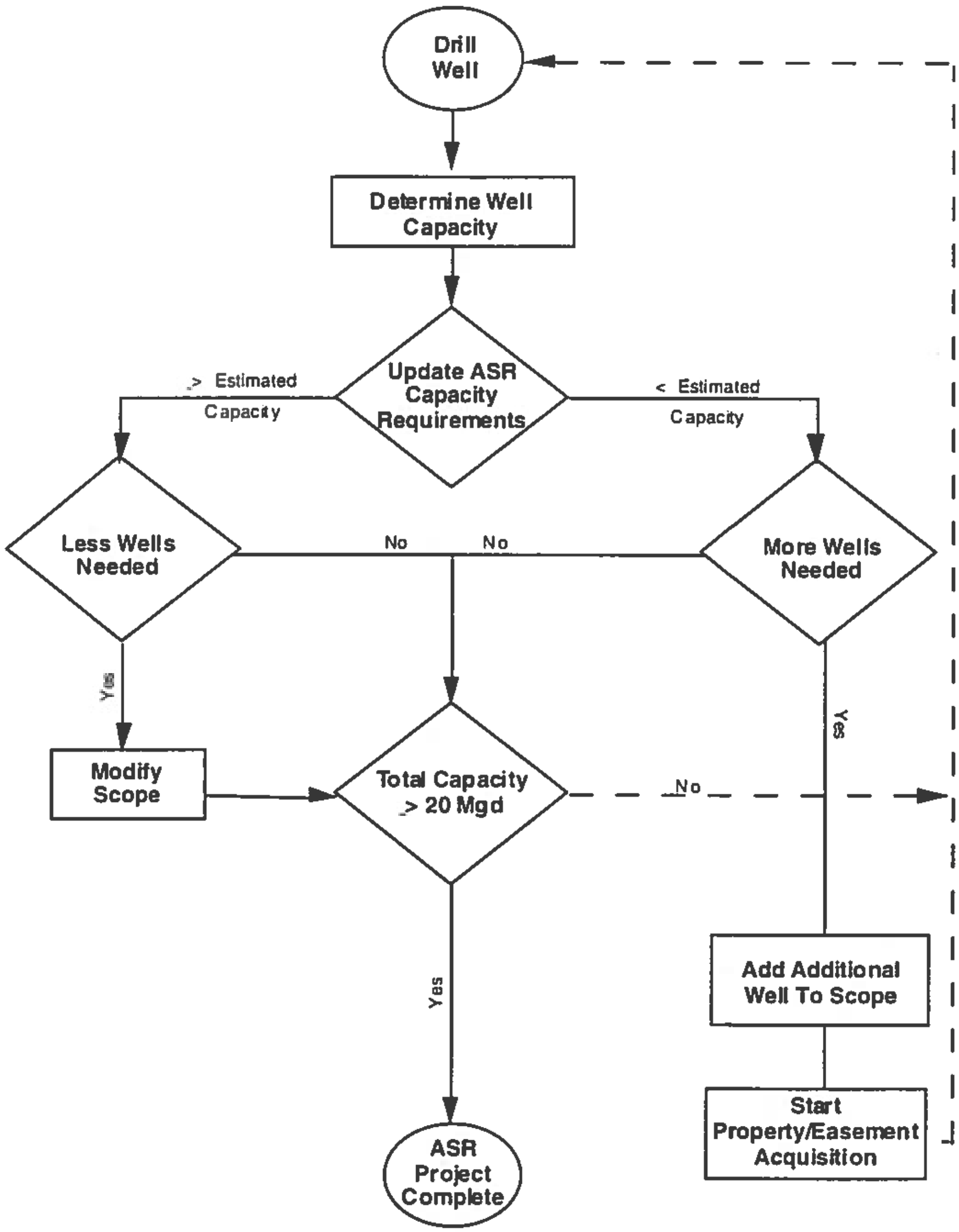


Figure 4-3
ASR Water Supply Project
Decision Flow Path

OPERATIONAL ISSUES

The operational issues associated with the ASR water supply system include water quality monitoring, well performance testing and rehabilitation, and availability of water for meeting peak water demands and emergency supply. A discussion of each of these operational issues follows.

Water Quality Monitoring

The water quality monitoring program has been developed in concert with the Oregon DEQ, and as described in Section 3 is set-up to monitor the integrity of existing groundwater quality, and to ensure that the quality of customer supply water is not compromised by the ASR project. The monitoring program consists of the three monitoring events: 1) new well sampling, 2) background sampling for wells in service, and 3) water quality sampling during withdrawal. The new well sampling is designed to occur once per well, whereas the background sampling for wells on-line is to occur at the onset of each withdrawal period after well injection, and the water quality sampling during the first 48 hours each time the well is put into operation. For planning purposes it is assumed that the background water quality sampling and sampling during withdrawal will occur once annually per ASR well location. Analyses performed for each monitoring event were described in Section 3 of this report.

Well Performance Testing and Rehabilitation

Well performance testing should be completed after each year of operation. Testing should occur annually at each well site between the summer pumping period and the winter injection period. Performance testing should include a step pumping test conducted using the existing pumping equipment in each ASR well (that was used in the previous season). The step test data should be appropriately analyzed and the determined efficiency compared to prior data. Where the well efficiency has declined below 10%, rehabilitation should be attempted. A description of individual well rehabilitation is provided in Section 3 of this report. It has been assumed that performance testing only would occur during the five year ASR implementation program. Although it is difficult to predict the need for rehabilitation, it is assumed that the City would budget rehabilitation of each well once following 5 years of operation. Additional performance testing should follow each rehabilitation effort.

Peak Water Availability

ASR source water is available to provide summer peaking of one operating condition. Following the completion, implementation and operation of facilities described in Year 3 work, the City will be able to modify its current operation of supply and supplement with ASR as needed. As the peak demands increase and equal the minimum delivery of the smallest booster supply pump from the Edwards, Fairmont or Boone Road pump stations, an equivalent ASR well can be started and the similar capacity booster pump turned off. This, in effect, will allow demands in pressure zone S-2 to be met from the ASR supply while the equivalent surplus capacity remains in the lower pressure zone.

This operating strategy would continue with ASR wells replacing capacity which has historically been delivered by booster pumps. One key is to match ASR well delivery to the capacity of the booster pump(s) which would normally be used. When demands within pressure zone S-2 are met or are exceeded by the ASR supply put into operation, the City will have two choices: 1) seek the combination of ASR pumps which equal, but do not exceed, S-2 demand, or 2) when PRV stations are complete, bleed excess ASR supply into the lower pressure zones. Maintaining an accurate amount of ASR storage will be necessary to determine the volume available for peaking during the period of demand.

Emergency Water Availability

As the need arises and surface supply from the Santiam River is either not available or insufficient to meet emergency conditions (major fire, main breakage, flooding, etc.) water can be provided from ASR storage. Initially, until PRV stations are constructed, ASR supply would be used to satisfy conditions in pressure zone S-2 while available surface supply would meet lower zone needs. When the PRV stations are complete, the ASR supply can be used to feed up to three separate locations in pressure zones S-1 and G-0. Completion of dedicated piping to pressure zone S-3 will also ASR supply to be directed to that location during an emergency.

Emergency operation can be automatic or manual depending upon City requirements. As discussed in previous paragraphs, the control setup of PRV stations can allow either form of operation.

PHASING AND SCHEDULE

The schedule for completing the Year 3 through Year 5 ASR water supply project is shown on Figure 4-4. It should be noted that the completion of the Year 3 well development is shown as mid-April 1997. This allows one month minimum of injecting surplus surface water supply into the ground for storage, such that by July 1997 withdrawal from the ASR wells may begin in time for meeting peak water demands. Three months per well site has been allowed for drilling, casing, pump testing, equipping, and constructing the well house. While this is an aggressive schedule, it is necessary for meeting the goal of having 10 mgd withdrawal rate of ASR supply water available by July 1997.

Two weeks has been allowed for drilling wells which are located in close proximity to each other. It is anticipated that drilling for ASR Well No. 4 can begin two weeks after the start of ASR Well No. 3, with both wells located at the Arlene Park site. One month has been allowed between the start of drilling the ASR Well No. 4, located at Arlene Park and ASR Well No. 5, located at Woodmansee Park. This additional time has been allowed to accommodate demobilization and mobilization of the drill rig, and site preparation. A two week window has been allowed between ASR Well No. 5 and ASR Well No. 8, because of their close proximity on the Woodmansee Park site. However, a month has been allowed for the start of drilling ASR Well No. 6 after the start of ASR Well No. 8. While located in the same general proximity, it is anticipated that the remoteness of ASR Well No. 5 and ASR Well No. 8 at Woodmansee Park may require additional time. Again, because of relative ease of access and proximity only two weeks has been allowed between the start of drilling for ASR Well No. 6 and ASR Well No. 7. It is stressed that any deviation which prolongs the completion of the ASR wells identified for the Year 3 plan, will result in the potential of having less than the water supply goal of 350 mg in storage or a withdrawal rate of 10 mgd by July 1997.

The schedule for designing, bidding, and constructing the 16" diameter east/west connection pipeline has been included on the schedule, as well. As can be seen from Figure 4-4, completion of the pipeline will follow completion of well development, but will meet the water supply on-line date of July 1991. Designing, bidding and constructing the north/south and S-3 emergency intertie pipelines is shown in Year 4. With respect to the S-3 emergency intertie ASR Well No. 3 and ASR Well No. 4 will be on-line for S-2 service by the end of Year 3, and would only require the pipeline to S-3 to complete the emergency intertie. The north/south pipeline would complete the enhancements for moving ASR supply water throughout the S-2 service area. The Woodmansee Park wells, ASR Well Nos. 5, 6, 7 and 8, will be complete by the end of Year 3 at which time it is recommended that the transmission pipeline design begin.

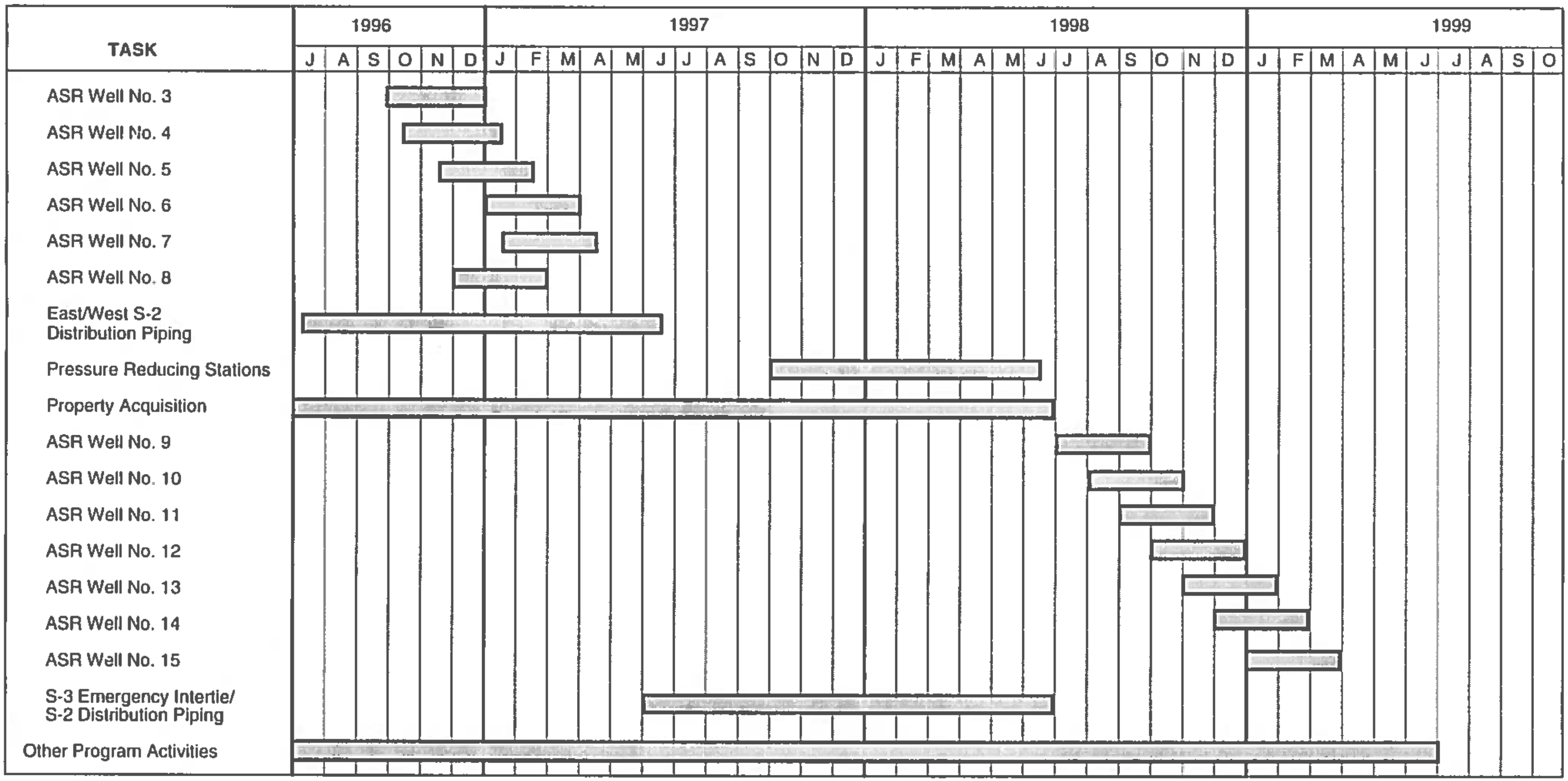


FIGURE 4-4
CITY OF SALEM - IMPLEMENTATION PLAN
SCHEDULE

684010

Critical elements for completion of this schedule are Notice to Proceed for Year 3 work by mid-September 1996 and the ability to obtain necessary power service to each site prior to startup of the equipment. Year 4 and 5 efforts will be contingent upon successful easement and property acquisition for proposed wells.

IMPLEMENTATION COSTS

The project costs for implementation of the ASR project include the capital costs of facilities, operational costs, and other related costs. Capital costs consist of well development and construction of ancillary facilities, and operational costs include routine monitoring programs and well rehabilitation. Other program costs include recommended programs for maintaining the integrity of ASR water quality, and ease of data collection and analysis. All costs are in first quarter 1996 dollars. These costs are facility planning level estimates having a potential variation from final costs of +30 and -15 percent. The costs for Year 3 through Year 5 for implementation of the ASR water supply project are summarized in Table 4-2.

The total ASR implementation costs for Year 3 through Year 5 is approximately $8,100,000 to $8,950,000. It is apparent from the cost summary presented in Table 4-2 that the greatest unknown in the implementation costs is easement/property acquisition. The dollar range shown for this element is based upon available information at the preparation of this document. As more data becomes available relative to easement/property acquisition, the costs for the element can be refined.

Capital Costs

The capital costs include the costs for developing the ASR wells, equipping the wells, and constructing ancillary facilities for the completion of the Year 3, Year 4 and Year 5 ASR water supply facilities. Estimated capital costs were developed based upon available unit cost data and results of the work completed for ASR Well No. 1 and ASR Well No. 2. Capital costs for well development, equipping the well, and construction of the well house include a contingency of 5 percent. Capital costs for ancillary facilities including the construction of additional distribution pipelines, pump to waste piping and the pressure reducing stations include a contingency of 10 percent, as well as 20 percent for engineering, administration, and legal services. The 20 percent for engineering, administration, and legal services is based on a conventional design, bid, and construct project versus a design/build project.

Operational Costs

The operational costs include those costs associated with hydrologic and water quality monitoring, and well rehabilitation. Routine maintenance, and power and chemical costs are not included in the operational costs. Costs for routine operation and maintenance would be based on current practice at the City, and would be in addition to the standard operation and maintenance costs the City occurs. The operational costs for water quality monitoring and well performance testing are conservative, and assume that all the developed wells will be in-service annually. These operational costs in Table 4-2 are based on annual use of each of the ASR wells (i.e. Year 3 - 8 wells and Year 5 - 15 wells). Beyond the Year 5 plan it is anticipated that costs for water quality monitoring and well performance testing will continue to be incurred. The level of future water quality monitoring beyond the Year 5 will need to be negotiated with the Oregon DEQ, and based on favorable water quality results during the Year 3 to Year 5 period may be reduced.

Table 4-2
ASR Implementation Cost Summary

YEAR 3		
Capital Costs		
Well Development		2,800,000
16 " East/west Pipeline		550,000
Pressure Reducing Stations		200,000
	Subtotal:	$ 3,350,000
Operational Costs		
Water Quality Monitoring		60,000
Performance Testing		40,000
	Subtotal:	$ 100,000
Other Program Costs		
Landslide Monitoring Wells		110,000
Reconstructed Monitoring Wells		115,000
Long-term Hydrologic Monitoring		30,000
Wellhead Protection Program		100,000
ASR System Database		20,000
Implementation Plan Update		50,000
	Subtotal:	$ 425,000
Total Year 3 Costs		**$ 3,875,000**
YEAR 4		
Capital Costs		
12" North/South Pipeline		250,000
16 "S-3 Emergency Intertie		275,000
Pressure Reducing Stations		200,000
	Subtotal:	$ 725,000
Operational Costs		
Water Quality Monitoring		15,000
Performance Testing		40,000
	Subtotal:	$ 55,000
Other Program Costs		
Long-term Hydrologic Monitoring		14,000
Implementation Plan Update		15,000
	Subtotal:	$ 29,000
Easement/Property Acquisition		$ 400,000 - $1,250,000
Total Year 4 Costs		**$ 1,209,000 - $2,059,000**
YEAR 5		
Capital Costs		
Well Development		$ 2,920,000
Operational Costs		
Water Quality Monitoring		65,000
Performance Testing		75,000
	Subtotal:	$ 140,000

Table 4-2 - continued
ASR Implementation Cost Summary

Other Program Costs		
Long-term Hydrologic Monitoring		14,000
Implementation Plan Update		50,000
Subtotal:	$	64,000
Total Year 5 Costs	**$**	**3,124,000**
Long-term Operating Costs		
Water Quality Monitoring		25,000
Data Acquisition and Recording		15,000
Performance Testing		75,000
Annual Costs	**$**	**115,000**

The level of effort for well performance testing and rehabilitation will be determined with experience. As more ASR wells in the Salem Heights aquifer are developed the greater the database of well performance. With increasing knowledge of ASR well performance in the Salem Heights aquifer, the level of effort required for future well performance evaluation can be tailored to best fit this area of ASR well development. A more tailored program will reduce the costs over time for performance testing.

Other Program Costs

Other program costs include the development of monitoring wells, a long-term hydrologic monitoring program including data collection and reporting, a wellhead protection program, and an ASR system database. An annual update to the ASR water supply implementation plan has also been provided. Updating the implementation plan concurrently with ASR well development will keep the project on track and will provide early identification of schedule delays. While these other program elements are not necessary for the rudimentary operation of the ASR system, they are necessary to preserve the integrity of the City's water supply and are recommended for compliance with State of Oregon requirements.

Appendix A

List of References

LIST OF REFERENCES

Golder Associates Inc., 1995, City of Salem Aquifer Storage and Recovery Pilot Project Technical Memorandum on Hydrogeology, report to Montgomery Watson Americas, Inc., August 30, 1995.

Golder Associates Inc., 1996a, Well Completion Report ASR Well No. 2, Woodmansee Park Salem, Oregon, report to Montgomery Watson Americas, Inc., February 5, 1996.

Golder Associates Inc., 1996b, Monitoring Well Construction Report Park Well No. 2 Woodmansee Park Salem, Oregon, report to Montgomery Watson Americas, Inc., February 26, 1996.

Golder Associates Inc., 1996c, City of Salem Aquifer Storage and Recovery Pilot Project Technical Memorandum on the ASR Pilot Test, report to Montgomery Watson Americas, Inc., March 29, 1996.

Golder Associates Inc., 1996d, City of Salem ASR Pilot Project Technical Memorandum on Groundwater Quality, report to Montgomery Watson Americas, Inc., March 29, 1996.

Golder Associates Inc., 1996e, City of Salem ASR Pilot Project Technical Memorandum on Landslide Evaluations, report to Montgomery Watson Americas, Inc., April 25, 1996.

Golder Associates Inc., 1996f, City of Salem Aquifer Storage and Recovery Project Monitoring Well ASRMW-1 Report, report to Montgomery Watson Americas, Inc., April 25, 1996.

Golder Associates Inc., 1996g, City of Salem Aquifer Storage and Recovery Project Hydrogeologic Testing in the Arlene, Cannery, and Friendship Wells, report to Montgomery Watson Americas, Inc., June 28, 1996.

Montgomery Watson, "Technical Memorandum 3.3 - Water Quality Evaluation", April 1996.

City of Salem *The Water System Master Plan.*, CH2M Hill, June 1994.

Appendix B

ASR Groundwater Sampling Plan

CITY OF SALEM
DEPARTMENT OF PUBLIC WORKS

AQUIFER STORAGE AND RECOVERY (ASR) PILOT PROJECT GROUNDWATER SAMPLING PLAN

May, 1995

1. PURPOSE

This technical procedure establishes a uniform methodology for collecting groundwater samples for chemical analysis that are representative of aquifer water quality.

2. APPLICABILITY

This technical procedure is applicable to all personnel engaged in the collection of groundwater samples from wells for purposes of chemical analysis.

3. DEFINITIONS

3.1 Dedicated Pump System

A dedicated pump system is a permanently installed device for removing water from a well. The system is not removed from the well and does not have the potential to become contaminated between uses.

3.2 Well Bore Storage Volume

Well bore storage volume is defined as the volume of water enclosed by the well casing and screen gravel/sand pack at equilibrium.

3.3 Bailer

A bailer is a tubular device with a check-valve at the top and/or bottom for collecting and removing groundwater from wells.

3.4 Non-dedicated Sampling Apparatus

Non-dedicated sampling apparatus is sampling equipment that may contact groundwater samples from more than one well. This term is also used to describe equipment that is only used for sampling a single well, but is removed from the well and could potentially become contaminated.

3.5 Groundwater Sample

A groundwater sample is defined as water acquired from a well for chemical analyses that is representative of groundwater within the aquifer or the portion of the aquifer being sampled.

3.6 Positive Pressure Pump

A positive pressure pump is a device for removing water from a well by forcing water to the surface through positive pressure when operated below the well's water level. A positive pressure pump may be operated electrically, mechanically, or by air/nitrogen pressure. Submersible impeller, bladder, and check valve pumps are common types of positive pressure pumps.

3.7 Negative Pressure Pump

A negative pressure pump is a device for removing groundwater from a well by suction (negative pressure). Peristaltic and centripetal pumps are common types of negative pressure pumps. The limitation for lifting water by suction is usually 20 to 25 feet. These pumps are only acceptable for non-volatile analytes and analytes that are not affected by aeration or changes in pH. They are useful as purging devices for shallow groundwater wells.

3.8 Sample Bottles

Sample bottles are containers specifically designed and prepared for storing liquid samples. Sample bottle type, material, size, and type of lid are specific for particular groups of analytes. Sample bottles must be properly cleaned and prepared by a laboratory or the manufacturer in accordance with References 4.2 and 4.3. Table 1 summarizes bottle type and preparation requirements.

3.9 Acceptable Material

Acceptable materials are defined as the only materials that are allowed to contact groundwater samples, and are dependent on the analytes being tested.

3.10 Permissible Pump

Permissible pumps are defined as pump systems that have minimal effect on water quality when used to obtain groundwater samples from wells. The use of permissible pumps is dependent on the analyses being conducted on the acquired samples. The parts of permissible pumps that will contact the groundwater sample contain only acceptable materials.

4. REFERENCES

4.1 Wood, W.W. (1976), "Guidelines for Collection and Field Analysis of Ground-Water Samples for Selected Unstable Constituents," Techniques of Water-Resources Investigations of the United States Geological Survey, Book 1, Collection of Water Data by Direct Measurement, Chapter D2.

4.2 U.S. EPA, 1986, Test Methods for Evaluating Solid Waste - (SW-846), U.S. EPA/Office of Solid Waste, Washington, D.C.

4.3 40 CFR 136

4.4 U.S. EPA, 1986, RCRA Ground-Water Monitoring Technical Enforcement Guidance Document, U.S. EPA/Office of Solid Waste, Washington D.C.

4.5 40 CFR 141

4.6 Procedure "Calibration and Maintenance of Measuring and Test Equipment."

4.7 Technical Procedure "Chain of Custody."

4.8 Technical Procedure "Water Level Measurement."

5. DISCUSSION

Groundwater samples shall be collected in quantities and types as directed by the Project Manager and project work documents. Prior to collection of groundwater samples, the well must be purged. All instruments used for field analyses shall be calibrated in accordance with Procedure "Calibration and Maintenance of Measuring and Test Equipment." All non-dedicated sampling equipment shall be decontaminated before and after each use. If directed by the Project Manager or as specified in project work documents, purge water and decontamination fluids shall be captured and contained for disposal. Samples shall be collected in properly prepared containers of the appropriate size and type. Sample containers will be provided by the contract laboratory, Coffey Labs. All samples shall be appropriately labeled and sealed. Samples shall be stored and transported in coolers. Chain of custody shall be maintained. The above will be provided by the contract laboratory.

Field notes should be taken during sampling by the Field Engineer. Field notes should document the sampling date, site location, sample ID number, and other parameters described in Exhibits C and E (attached). Field notes may be collected in a bound notebook, with carbon copies. One set of notes should be retained by the Field Engineer, with the carbon copies forwarded to the Project Manager. All variations from established procedure shall be documented on the Procedure Alteration Checklist (Exhibit E) and shall be approved by the Project Manager.

6. RESPONSIBILITIES

6.1 Field Engineer

The City of Salem, Department of Public Works Field Engineer is responsible for sample collection, sample custody in the field, preservation, field testing, total and accurate completion of data sheets, sample shipment and delivery of data to the Project Manager, all as described in this technical procedure.

6.2 Project Manager

The Montgomery Watson Project Manager has overall management responsibilities for the project, is responsible for designing the sampling program, for arranging the logistics of the program, and for providing any required clarifications in the use of this procedure. The Project Manager is responsible for maintaining project files and filing project documents, project correspondence, sample integrity data sheets, chain of custody forms, field report forms, generated data and other associated and pertinent project information.

7. EQUIPMENT AND MATERIALS

- If wells are equipped with permissible and dedicated pump systems, equipment to operate the dedicated pump systems (i.e., air compressor, compressed air or nitrogen cylinders, electric generator, etc.) and non-dedicated sampling apparatus such as surface discharge tubing and valving or bailer(s) for sampling free floating product may be necessary.

- If wells do not have permissible and dedicated pump systems, permissible pump systems or bailers and accessories of small enough diameter to enter the wells will be necessary. All equipment that could contact the sample shall be made of acceptable materials.

- Sample bottles (properly cleaned and prepared in accordance with Reference 4.2 or 4.3), and preservatives appropriate for the parameters to be sampled (see Reference 4.2 or 4.3).

- Field test equipment

  - thermometer
  - pH meter and standards
  - conductivity meter and standards
  - dissolved oxygen meter (optional)
  - turbidity meter and standards

- Depth to water measuring device

- Well specifications

- Sample Integrity Data Sheets (Exhibit C)

- Carbon paper, if necessary

- Chain of Custody Forms

- Coolers and ice packs

- Distilled or deionized water

- Cleaning equipment and solutions

- Indelible ink pens and felt-tip markers

- Sample labels and seals

- Container(s) for capturing, containing, treating and measuring waste decontamination solutions, if necessary.

- Procedure Alteration Checklist Forms (Exhibit E)

8. PROCEDURE

8.1 General Considerations

8.1.1 Decontamination

All non-dedicated sampling equipment that may contact the sample must be decontaminated before and after each use. Non-dedicated pumps or bailers require decontamination of internal and external parts prior to being lowered into the well. Non-dedicated equipment shall first be washed with clean tap water (whose chemistry is known and acceptable), non-phosphate detergent, and rinsed with clean tap water. For inorganic analytes a weak hydrochloric acid (HCl) solution shall be used for the second wash. For organic analytes, reagent-grade methanol shall be used for the second wash. A final rinse with organic-free distilled/deionized water shall complete the decontamination. At a minimum, all acid and methanol wash solutions must be captured (see Section 8.4.2).

8.1.2 Sample Quantities, Types, and Documentation

Samples shall be collected in quantities and types as directed by the Project Manager or as specified in the project work documents. Field notes shall be used to document daily site activities and sample collection (see Section 8.5). Samples shall be transferred to the analytical laboratory under formal chain of custody, which shall be documented and maintained in accordance with procedure "Chain of Custody".

8.1.3 Sample Containers

All sample bottles must be properly cleaned and prepared as specified in reference 4.2 or reference 4.3. All groundwater samples shall be labeled and sealed (see Section 8.5) and immediately placed in 4 degrees C coolers with securely closed lids for storage and transport. Samples must be received by the analytical laboratory in sufficient time to conduct the requested analyses within the specified holding time.

8.1.4 Acceptable Materials

Acceptable materials that may contact any groundwater sample are stainless steel and fluorocarbon resin (Teflon, PTFE, FEP, or PFA). Glass is an acceptable material for contacting samples except when silica or fluoride analysis are to be performed. Plastics (PVC, polyethylene, polypropylene, tygon) are an acceptable material for contacting samples when the analyses are for inorganic analytes (metals, radionuclides, anions, cations).

8.1.5 Sample Acquisition

Groundwater samples shall be removed from the well with the use of a permissible pump or bailer. Electric positive-pressure pumps made of acceptable materials as defined in Section 3.0 are permissible to use for acquiring any groundwater sample. Air/nitrogen pressure activated positive-pressure pumps made of acceptable materials are permissible to use for acquiring any groundwater sample if the air/nitrogen does not contact the sample. Positive-pressure pumps operated by mechanically forcing water through check valves (e.g.. Hydrostar HS 8000) are permissible for acquiring any groundwater samples. Bailers made of acceptable materials are permissible for acquiring any groundwater sample.

Peristaltic pumps and air-lift pumps are not preferred for acquiring groundwater samples but are permissible when samples are to be analyzed for analytes that are not volatile, are not affected by aeration, and are not affected by changes in pH.

Other types of pumps (peristaltic, centrifugal, air lift, recirculation, etc.) may be used for purging groundwater from wells prior to sample acquisition, if: (1) pump materials contacting well water are acceptable; (2) pumping does not aerate or change the pH of the remaining well water; and (3) pumped water does not mix with remaining well water during pumping or after the pumping is stopped.

8.2 Groundwater Sample Acquisition

8.2.1 Purging the Well

The pump or bailer shall be used and operated in accordance with the manufacturer's operational manual. Before collecting the actual groundwater sample, a minimum of three (3) well bore storage volumes of water shall be purged from the well by pumping. Calculate this volume by measuring the depth to water and subtracting this depth from the total depth of the well. If a gravel/sand pack surrounds the screen the pore volume of the gravel/sand pack (assume a porosity of 25 percent if unknown) shall be added to the total well volume. While purging water from the well, the conductivity, pH, temperature, dissolved oxygen (optional) and turbidity of the water shall be periodically measured. If the conductivity (within 10%), pH (within 0.1 pH units), temperature (within 0.5 degree C), dissolved oxygen (within 10%) or turbidity (within 10% and less than 5 NTU) of the water has not stabilized when a minimum of three (3) well volumes have been purged, then continue to purge water until these parameters stabilize as specified above. If the parameters of interest in the investigation include VOCs, care must be taken to ensure that purging does not induce degassing within the well. Where the well screen and sand pack are completely below the water table, the rate of purging should be controlled such that it does not draw the water level in the well below the top of the well screen. Where the well screen and sandpack are intersected by the groundwater level, the rate of purging should correspond with the rate of sampling, if continuous sampling methods are used. Large drawdowns in water table wells should be avoided. More details are provided in Reference 4.4.

8.2.3 Samples for Major Cation, Metal and Metallic Radionuclide Analyses

Samples for major cations metal and metallic radionuclide analyses shall be collected directly from a positive- pressure pump discharge port or bailer in appropriate sample bottles with Teflon lined lid and appropriate preservative. Samples should not be allowed to overflow the sample bottle and shall not be filtered.

In addition, if toxic metal (see reference 4.5) or priority pollutant metal analyses are to be performed (see reference 4.2), an unfiltered aliquot will also be obtained directly from a permissible positive-pressure pump discharge port or from the bailer into appropriate sample bottles.

8.2.4 Samples for Extractable Base-Neutral/Acid Organic, Phenolic Compound, PCB and/or Pesticide Analyses

Samples for extractable base-neutral/acid organic, phenolic compound, PCB and/or pesticide analyses shall be collected directly from a positive- pressure pump discharge port or bailer in appropriate sample bottles with Teflon lined lid and appropriate preservative. Samples should not be allowed to overflow the sample bottle and shall not be filtered.

8.2.5 Samples for Purgeable Volatile Organics

Samples for purgeable volatile organics shall be obtained after other bottles (for other analytes) have been acquired for each well. Samples for purgeable volatile organics shall be pumped from the well using a permissible positive-pressure pump or bailer and shall be collected directly from the pump discharge tube or bailer into properly cleaned and prepared 40 ml or 125 ml glass vials to overflow approximately 2 to 3 vial volumes. Contact with air and sample agitation should be minimized. If necessary, pumping rates may be significantly reduced during sampling for volatile organics. These samples shall not be filtered or preserved. Immediately after collection, a Teflon lined silicon septum cap shall be tightened onto the vial. There should be no air bubbles remaining within the vial once the cap has been fastened: if air is present, a new sample shall be taken by the same procedure.

8.2.6 Samples for Major Anion and Biological Oxygen Demand (BOD) Analyses

Samples for major anions (chloride, fluoride, sulfate, alkalinity, acidity, total silica, bromide) shall be collected directly into appropriate sample bottles from the port of the pump or from the bailer. These samples do not require filtration, but may be filtered, if desired. Preservatives shall not be added.

8.2.7 Samples for Total Phosphate and Orthophosphate Analyses

Groundwater samples for total phosphate and orthophosphate analyses shall be collected directly from a positive- pressure pump discharge port or bailer in appropriate sample bottles with Teflon lined lid and appropriate preservative. Samples should not be allowed to overflow the sample bottle and shall not be filtered.

8.2.8 Samples for Nitrogen Compound, Chemical Oxygen Demand, Oil and Grease, and Total Organic Carbon Analyses

Groundwater samples for nitrogen compound, chemical oxygen demand, oil and grease, and total organic carbon analyses shall be collected directly into appropriate sample bottles from a permissible positive pressure pump discharge port or from the bailer. These samples shall not be filtered and shall be preserved with appropriate preservative.

8.2.9 Samples for Analysis of Total Dissolved Solids

Groundwater samples for analyses of total dissolved solids shall be collected directly into appropriate sample bottles from a permissible positive pressure pump discharge port or from the bailer. Samples shall not be preserved with additives.

8.3 <u>Field Analyses</u>

8.3.1 Calibration of Instruments

All instruments used for field analyses shall be calibrated according to manufacturer's instructions. Each instrument should be accompanied by a copy of the manufacturer's operation manual.

8.3.2 Water Temperature

A pocket thermometer shall be used to measure the temperature of the water on an aliquot of purged water obtained just before or after sampling. The thermometer reading shall be allowed to stabilize and shall be recorded to the nearest 0.5 degree centigrade. The thermometer shall be rinsed with distilled or deionized water before and after each use.

8.3.3 pH Measurement

A pH meter shall be used to measure the pH of the sample on an aliquot of purged water that was obtained just before or after sampling. Measurements shall be made immediately on the obtained aliquot. (Note: If possible, measure pH continuously on the purged water in a closed flow-through system.) Calibration shall be in accordance with the manufacturer's procedures (provided with the instrument). Calibration shall be performed with standardized buffered pH solutions and conducted prior to each use. Before and after each reading, the probe shall be thoroughly rinsed with distilled or deionized water. The pH shall be recorded to one-tenth (or one-hundred if meter is stable enough) of a pH unit.

8.3.4 Conductivity Measurement

A conductivity probe shall be used for conductivity measurement on an aliquot of purged water obtained just before or after sampling. Measurements shall be made as soon as possible on the obtained aliquot. The meter shall be calibrated in accordance with manufacturer's procedures (provided with the instrument) with standardized KCL solutions. At a minimum calibration shall be performed at the beginning and ending of each day's use. The conductivity shall be recorded to two significant figures. The temperature of the sample at the time of conductivity measurement shall also be recorded. The probe must be thoroughly rinsed with distilled/deionized water before and after each use.

8.3.5 Dissolved Oxygen Measurement

A dissolved oxygen meter is used to measure dissolved oxygen (DO) in water samples. Measurements shall be made immediately on aliquots obtained just before or after sample acquisition. (Note: If possible, measure DO continuously on the purge water in a closed flow-through system.) The meter shall be calibrated in accordance with the manufacturer's procedures (provided with the instrument) using distilled/deionized water that has been allowed to equilibrate with the atmosphere at a given elevation. The salinity adjust shall be adjusted to the approximate salinity of the water. Measure the temperature and concentration of dissolved oxygen in the sample while the salinity is on the fresh setting. The probe must be thoroughly rinsed with distilled or deionized water before and after each use. Measurements shall be recorded to the nearest 0.1 ppm concentration.

8.3.6 Turbidity Measurements

A turbidity meter shall be used to make turbidity measurements on aliquots of water samples obtained just before or after sample acquisition. Measurements shall be made as soon as possible on the obtained aliquot. Operation and calibration shall be in accordance with the manufacturer's procedures (provided with the instrument). Standardized formazin solutions shall be used for calibration. The instrument shall be calibrated at least once during the purging and sampling of each well. The outside of the glass vials used for containing the aliquot for measurement must be wiped thoroughly dry before and after each use. Measurements shall be recorded to the nearest 0.1 NTU when less than 1 NTU; the nearest 1 NTU when between 1 and 10 NTU; and the nearest 10 NTU when between 10 and 100 NTU.

8.4 <u>Capture and Disposal of Purge Water and Decontamination Solutions</u>

8.4.1 Decontamination Waste Solutions

Decontamination waste solutions that are generated during groundwater sampling include: spent detergent wash solutions; spent tap water rinses; any spent weak acid rinses, any spent methanol rinses; and spent final distilled/deionized water rinses. All spent acid and methanol rinses shall be captured and contained in plastic buckets or drums. Other spent decontamination waste solutions shall be captured and contained in appropriately sized buckets or drums, if a reasonable potential exists for the spent solutions to contain hazardous substances.

8.5 Documentation

Documentation for sampling groundwater includes labeling sample bottles; collection of field notes and Chain of Custody Records.

8.5.1 Sample Labels

Samples shall be immediately labeled. Labels shall be water proof. Information shall be recorded on each label with indelible ink. All blanks shall be filled in (N/A if not applicable). Groundwater sample designations will be as specified in the project work documents or by the Project Manager.

8.5.2 Field Notes

Field notes shall be used by the Field Engineer to record daily activities. Data shall be recorded in the field notebook in chronological format. The time of each recorded event shall be included. The original field notes shall be retained by the Field Engineer. Copies shall be given to the Project Manager and Task Leader.

8.5.3 Chain of Custody Records

Chain-of-Custody Records will be used to record the custody and transfer of samples in accordance with procedure "Chain of Custody." These forms shall be filled in completely (N/A if not applicable). The original form must accompany the samples to the analytical laboratory to be completed and returned to for filing by the Project Manager.

8.6 Procedure Alteration Checklist

Variation from established procedure requirements may be necessary due to unique circumstances encountered on individual projects. All variations from established procedures shall be documented in the field notes and reviewed by the Project Manager .

The Project Manager may authorize the Field Engineer to initiate variations as necessary. If practical, the request for variation shall be reviewed by the Project Manager and the QA Manager prior to implementation. If prior review is not possible, the variation may be implemented immediately at the direction of the Field Engineer, provided that the Project Manager is notified of the variation within 24 hours of implementation, and field notes are forwarded to the Project Manager and QA Manager for review within 2 working days of implementation. If the variation is unacceptable to either reviewer, the activity shall be re performed or action shall be taken as appropriate.

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Groundwater Recharge for an Aquifer Storage and Recovery Pilot Program

HYDROLOGIC FEASIBILITY REPORT

December 1994

MONTGOMERY WATSON

Golder Associates

HYDROGEOLOGIC FEASIBILITY OF GROUNDWATER RECHARGE FOR AQUIFER STORAGE AND RECOVERY PILOT PROGRAM

INTRODUCTION

The aquifer storage and recovery (ASR) project is a cornerstone element of the City of Salem's recently adopted Water System Master Plan. Under the Master Plan, ASR is to provide both a secondary source of supply and additional distribution storage. This source is to be used to meet peak day and seasonal demands as well as provide a source of supply in case of any disruption of the City's main North Santiam surface supply.

Source water for the ASR project will be water taken from the City of Salem distribution system. Water will be injected into the ASR wells during the low demand / high flow periods (winter months). Water would be withdrawn during the high demand / low flow periods (summer months) and during emergency situations. This pattern of injection and withdrawal will reduce the impact of growth in water use in Salem on low flow withdrawals of water from the North Santiam.

The area that has been selected as the site for the ASR wellfield is the Salem Heights. This area is underlain by Columbia River Basalt. Within this basalt is a vesicular (porous) section of basalt identified as between 10 to 100 feet in thickness that could be used to store and subsequently recover recharged water. The target aquifer is a confined zone overlain by low-permeability dense basalt and underlain by low-permeability sedimentary deposits. The aquifer appears to be of limited extent, pinching out to the south and east. To the north the basalt dips below younger Troutdale sediments. To the east the basalt is bounded by landslide deposits.

PREVIOUS INVESTIGATIONS

Past investigations have indicated that recharge of water in the Salem Heights basalt can be achieved. In the 1960's the USGS conducted a study of ASR using Woodmansee Park Well # 2 (see Appendix A: Foxworthy, B.L. *Hydrologic Conditions and Artificial Recharge Through a Well in the Salem Heights Area of Salem, Oregon*. U.S. Geol. Survey Water Supply Paper 1594-F, 1970). This well is an old water supply well once used by the Salem Heights Water District, which the City of Salem now owns since annexing that District. In 1977, J. M. Montgomery Engineers (JMM) (the predecessor of Montgomery Watson) expanded the USGS work considerably (see Appendix B: J.M. Montgomery, *Report on Groundwater Recharge, Park No. 2 and Arlene Wells.* October 26, 1977).

The USGS study addressed well efficiency, potential storage, water level rise in response to recharge, and physical/chemical changes in response to recharge. The JMM study involved the injection of about 150 million gallons into the Park Well #2 and Arlene wells over a three and a half month period in 1977. The injection resulted in a water level rise of between 22 to 24 feet in the Fir Dell and Cannery observation wells. The report provided additional water quality analysis from the Park 2 well, and analyzed the quality of the recovered groundwater. There was little change in the quality of the recovered water from that injected.

In the City of Salem's Master Plan additional work was conducted to characterize the Salem Heights geology and hydrogeology. Local wells were inventoried and geophysical logging of Park Wells # 1 and # 2 was conducted. This work indicated that the lower aquifer is at least 29 feet thick (the zone open in Park well #2). It suggested that the aquifer is 50 feet thick (the geologic thickness of the lower basalt flow {280 to 330 feet below ground surface]), even though the lower part of the Park well # 2 has not been logged to verify this conclusion because the well is caved. Cross sections to estimate the extent of the aquifer were developed These cross sections indicate that the lower aquifer extends eastward and northward for at least 1.5 miles and one mile, respectively from the Park wells. They show the lower aquifer pinching out the south and feeding landslide deposits to the west.

Water-level rise data from three observations wells (Park well #1, Arlene and Fir-Dell) from the USGS test have been evaluated using a distance-drawdown technique to estimate aquifer properties. Based upon this technique, the aquifer properties are estimated to be: transmissivity 14,495 ft^2/day, and storativity 4×10^{-4}. The distance recharge plot is shown in Figure 1.

The aquifer properties were also estimated using a numerical transient model by simulating the USGS 15-day injection test and comparing predicted heads at the three observation wells to those observed during the test. This evaluation indicated a transmissivity of approximately 12,500 ft^2/day and a storativity of 5×10^{-3}.

The effect on water level rise of recharging water to the basalt was also estimated to preliminarily determine whether storage of 350 MG is feasible. Simulations indicated a potential water level rise of between 60 to 80 feet over a 10-square mile area (assuming a bounded aquifer system and a storativity of 5×10^{-3}). Since the potentiometric head in the lower aquifer is estimated to be about 200 feet below ground surface (at Park Well # 2 approximate elevation of 185 feet), the pressure head increase could increase the head in the lower aquifer to between 245 to 265 feet amsl. A lower storativity would result in a greater increase in pressure. This was an idealized representation of the system, but served to indicate that the City's storage goal is possible given the limited information on the hydrogeology of the area. This estimate of the increase in water levels during recharge is consistent with that observed in the 1977 JMM study of ASR and substantiates the estimate of aquifer properties.

ASR PILOT TEST PROGRAM

For the current pilot test, water will be taken from distribution pipelines in Woodmansee Park, and injected into Park Well # 2. Park Well # 1, another old Salem Heights Water District well, will be converted into a monitoring well. Water which is extracted during the course of the testing will be discharged to waste through a storm sewer connection. Under the pilot test program, approximately 43 million gallons of treated drinking water will be injected over a 30 day period (about 1.4 MGD). The water will be stored for 30 days, under observation, and then withdrawn over another 30 day period.

The Master Plan calls for a minimum recovery capacity of 10 million gallons a day (MGD) from the ASR system, although a capacity of 20 to 30 MGD is a more desirable target. The Master Plan also calls for aquifer storage capacity of up to 350 MG. If the ASR Pilot Project finds that these goals cannot be attained, then the schedule for other, more costly elements of the Water System Master Plan must be accelerated.

The schedule for the project calls for the pilot test work to be completed during the winter of 1994 - 1995. Evaluation of the pilot tests and planning for a full scale system would occur during the spring and early summer of 1995. Design of the full scale system occurs in the fall of 1995 and the winter of 1995 - 1996. The number, size, and location of wells, pipelines, and other facilities which may be needed to make a fully functional system will be determined based on the results of the pilot testing. Construction of the full scale system will be conducted in the spring through fall of 1996. This allows full scale storage of water in the winter of 1996 - 1997, with first recovery and use in the summer of 1997.

APPENDIX A

Hydrologic Conditions and Artificial Recharge Through a Well in the Salem Heights Area of Salem, Oregon

By BRUCE L. FOXWORTHY

ARTIFICIAL RECHARGE OF GROUND WATER

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1594-F

Prepared in cooperation with the Salem Heights Water District

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UNITED STATES DEPARTMENT OF THE INTERIOR

WALTER J. HICKEL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

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CONTENTS

	Page
Abstract	F1
Introduction	2
Purpose and scope of the investigation	2
Location and extent of the area	2
Related investigations	4
Acknowledgments	5
Well-numbering system	5
The hydrologic system and geologic controls	6
Character and extent of the basalt	7
Occurrence of water in the basalt	8
The main confined aquifer	10
Ground-water recharge and movement	11
Water-level fluctuations	14
Source and treatment of the recharge water	15
Methods of study and equipment	15
Preliminary evaluation	16
Adequacy of supply of recharge water	17
Storage capacity and permeability of the aquifer	17
Water temperatures	18
Clogging	18
Sediment	18
Chemical reactions	19
Organisms	20
Air	20
Recovery of injected water	21
Suitability of recovered water	23
Recharge well and accessory equipment	23
Observation wells	25
Experimental procedures and instruments	27
Recharge and pumping tests	28
Significance of the tests	31
Changes in the physical and chemical character of the ground water	31
Effects on the aquifer and the recharge well	32
Buildup of water levels	32
Specific capacity	33
Recovery of the injected water	35
Methods and techniques for further artificial recharge	36
Conclusions	38
Selected references	39

ILLUSTRATIONS

		Page
PLATE 1.	Geologic map of the Salem Hills area	In pocket
2.	Hydrographs of the recharge well (8/3W–10K4) and seven observation wells for the period February–November 1962, South Salem area	In pocket
FIGURE 1.	Index map showing location of report area	F3
2.	Sketch illustrating the well-numbering system	6
3.	Diagrammatic section showing downward migration of ground water through unlined parts of wells that tap the basalt	13
4.	Map showing contours on the potentiometric surface of the main confined aquifer before and after artificial-recharge tests, 1962	22
5.	Schematic diagram of piping and equipment at the recharge well, 8/3W–10K4	24
6.	Graph showing changes in specific capacity of the injection well during recharge tests 2 and 3	30

TABLES

		Page
TABLE 1.	Summary of recharge and pumping tests, well 8/3W–10K4	F45
2.	Records of selected drilled wells in the Salem Heights area	46
3.	Drillers' logs of wells	48
4.	Chemical analyses of waters from the Salem Heights area	52
5.	Suspended sediment in waters sampled during artificial-recharge study at Salem Heights	54

ARTIFICIAL RECHARGE OF GROUND WATER

HYDROLOGIC CONDITIONS AND ARTIFICIAL RECHARGE THROUGH A WELL IN THE SALEM HEIGHTS AREA OF SALEM, OREGON

By BRUCE L. FOXWORTHY

ABSTRACT

In the Salem Heights area of Salem, Oreg., pumping from wells that tap a permeable zone of limited extent in basalt of the Columbia River Group caused serious year-to-year declines of ground-water levels. To determine the feasibility of reducing these declines by artificially augmenting the natural recharge and to develop techniques applicable to a municipal program of artificial recharge, a series of tests was made jointly by the Salem Heights Water District and the U.S. Geological Survey. A total of 24.5 million gallons of surplus water was purchased from the public-supply system of the city of Salem and injected under pressure into one of the municipal wells through the existing pump column during three periods, ranging in duration from 1 to 15 days, at an average injection rate of about 830 gallons per minute. The recharge water contained abundant dissolved air and, at times, excessive sediment; in other respects it was of excellent quality and was compatible with the native ground water. Before the experiments, water in the main aquifer contained unusually large amounts of dissolved oxygen, which apparently was introduced by water cascading from higher zones within unlined intervals of the wells.

As a result of the injection, the specific capacity of the well (ratio of pumping yield to drawdown) was reduced temporarily because of clogging of the water-bearing material near the well by sediment and, probably, by bubbles of air which came out of solution in the recharge water. Following each of the last two periods of injection it was necessary to surge the well by intermittent pumping to restore the specific capacity.

The artificial recharge had no apparent deleterious effects on the quality of the ground water. Sediment that was injected was virtually all removed from the recharge well during pumping and surging, and the chemical quality and bacteriological purity of the ground water did not deteriorate.

Pressure rise from the injected water spread rapidly through the permeable aquifer, but the residual buildup of ground-water levels was soon masked by a seasonal rising trend of levels. The geologic and hydrologic conditions, however, preclude the escape of substantial volumes of the recharge water from the Salem Heights area. The conditions appear to be favorable for further artificial recharge of the main aquifer. Changes in the specific capacity of the recharge well provide valuable guidance for subsurface injection operations.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

In 1960, the Salem Heights Water District and the residents then served by it faced a severe shortage of water. The water district, which supplied most of the water for a 3¼-square-mile suburban area adjacent to Salem, Oreg., owned 12 wells and pumped as much as 260 million gallons of ground water per year. Most of the water, however, was obtained from three wells that tap the same highly productive aquifer. Increasing pumpage associated with rapid suburban development of the area had resulted in progressive declines of water levels in the most productive wells to an extent that dewatering of the principal aquifer was inevitable unless withdrawal from it were decreased or recharge increased.

After three deep wells drilled during 1958–60 failed to increase appreciably the capacity of the water district well system, the district arranged to purchase water from the city of Salem. Upon completion of a booster-pump station and pipeline in August 1961, additional water became available to help meet the large summertime demands within the district; consequently, pumping from the public-supply wells was decreased. The interconnection of the two water systems raised the possibility of artificially recharging the Salem Heights ground-water reservoir by using surplus water from the Salem system to build up the supplies of ground water for future long-term and emergency needs.

The Salem Heights Water District, with the concurrence of the Oregon State Engineer, requested the U.S. Geological Survey to make a study of the technical feasibility of artificially recharging the principal aquifer and to develop practical techniques that could be used by personnel of a small water-supply agency in a continuing program of artificial recharge. The investigation consisted of a preliminary evaluation of the suitability of conditions for artificial-recharge tests, a study of the geologic and hydrologic conditions in the area, and the conduct and interpretation of artificial-recharge experiments in which water from the Salem water system was injected through one of the water district's wells.

The investigation was financed cooperatively by the U.S. Geological Survey and the Salem Heights Water District, and personnel of both agencies participated in the collection of the field data.

LOCATION AND EXTENT OF THE AREA

Salem Heights is the name given to a rolling upland area of indefinite extent near the southern limit of the city of Salem. It is included in the northeastern part of the more extensive Salem Hills area (fig. 1).

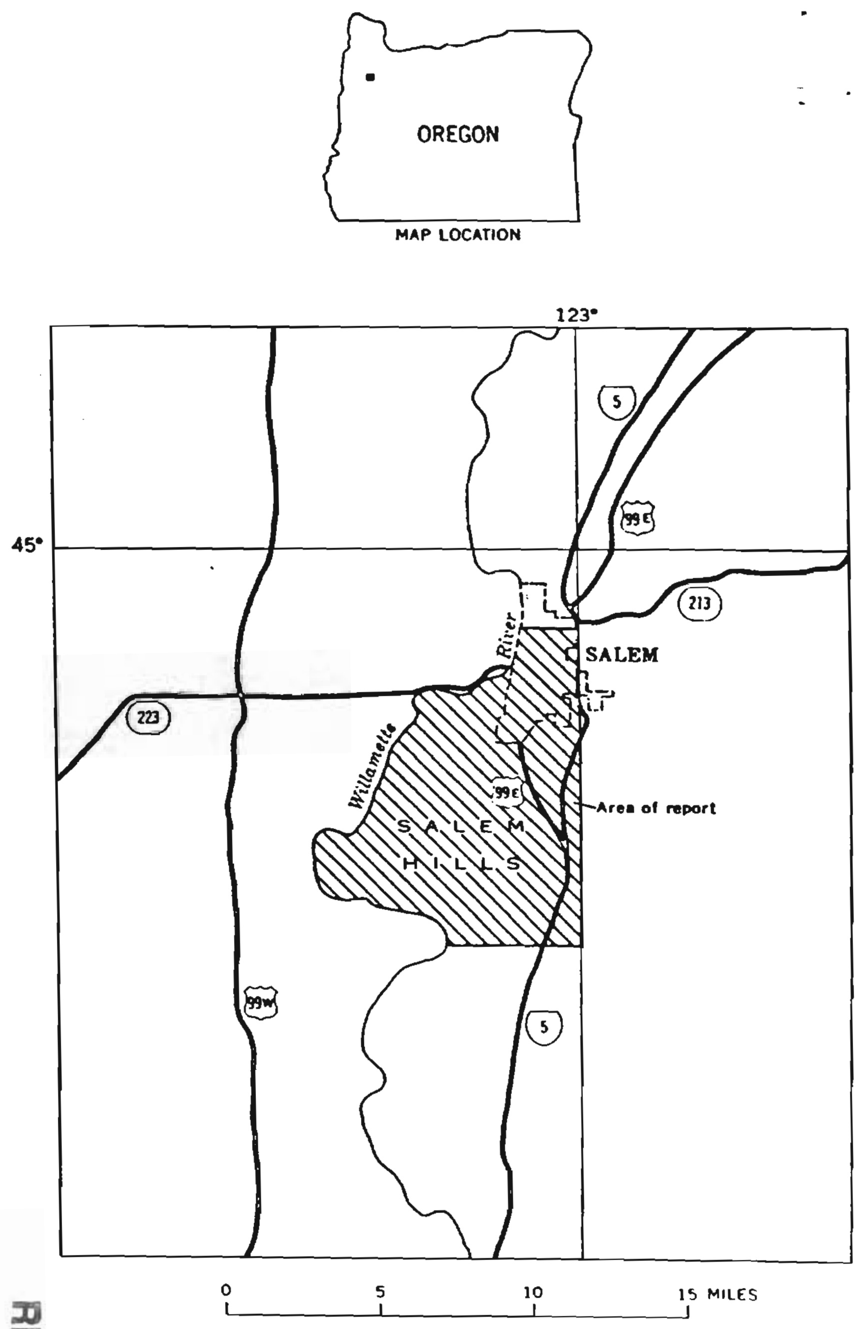

FIGURE 1.—Location of report area.

The Salem Hills area includes about 60 square miles and rises southward from the city of Salem at an altitude of about 200 feet above mean sea level to an altitude of slightly more than 1,100 feet at Prospect Hill. The southern and western boundaries of the Salem Hills area are steep bluffs that descend to the flood plain of the Willamette River. The eastern boundary is formed by small valleys that separate the Salem Hills from similar upland areas farther east.

Except for the geologic reconnaissance, which covered most of the Salem Hills area, the fieldwork for this study was mostly confined to sections 3, 9, and 10, T. 8 S., R. 3 W., which include all the productive wells of the Salem Heights Water District.

RELATED INVESTIGATIONS

Although artificial recharge through wells has been accomplished in several other parts of the country, only two controlled studies of such recharge in wells that tap water-bearing zones in basalt had been made before the beginning of this investigation. The previous studies were at Walla Walla, Wash. (Price, 1961), and The Dalles, Oreg. (Foxworthy and Bryant, 1967). During the first study, about 23 million gallons of surface water was injected into the basalt through a municipal-supply well of the city of Walla Walla at rates ranging from 630 to 670 gpm (gallons per minute). The experiment was considered to be successful because the injected water caused a rise of the water level and, therefore, increased the volume of ground water in storage in the vicinity of the well. However, the injection caused a decrease in the yield and specific capacity (pumping yield divided by drawdown of water level) of the recharge well, most of which was probably due to partial clogging of the water-bearing materials in the vicinity of the wells by bubbles of air.

During the second study, 81.4 million gallons of surplus treated stream water from The Dalles municipal supply was injected at moderately high pressures through one of the city's supply wells. Injection was at an average rate of about 1,500 gpm, the water being cooler than the native ground water by about 6°–13°C (11°–23°F). A temporary reduction in the specific capacity of the recharge well was due to (a) increased viscosity of the ground water caused by the cooling effect of the recharge water; (b) clogging of the aquifer materials near the well by bubbles of air; and (c) in at least one experiment, by a chemical floc that was introduced into the well with the recharge water. However, the specific capacity of the recharge well was restored by surging, and the experiments were considered to be proof of the technical feasibility of recharging the basalt aquifers, although the recharge water spread rapidly away from the well. Experience and data gained during the experiments at Walla Walla and The Dalles have proved to be valuable in the planning and conduct of the present study.

Among artificial-recharge experiments that provided helpful guidance to the present investigation was an exhaustive and well-documented series of subsurface-injection studies in the Grand Prairie region, Arkansas. Various aspects of those studies are described in a series of reports by Sniegocki and coworkers (U.S. Geol. Survey Water-Supply Paper 1615, chapters A–G).

Prior to the present study, the general geology of the Salem Hills and adjacent areas to the east had been mapped and described by T. P. Thayer (1939). Also, geologic and ground-water data from the Salem Heights area were being gathered concurrently with this study by Messrs. J. E. Sceva and W. S. Bartholomew, of the office of the Oregon State Engineer, for an evaluation of relations between ground-water withdrawals and water-level declines in the area.

ACKNOWLEDGMENTS

The investigation was facilitated by the assistance of many persons. The excellent cooperation of the water district officials and personnel made possible the collection of many important data that otherwise would not have been available. Valuable assistance and information concerning the district's water-supply facilities were furnished by the firm of Clark & Groff Engineers, Inc., and data pertaining to the district's wells and pumping equipment were supplied by the Stettler Supply Co.

The United Growers, Inc., permitted the use of a deep well for observation purposes. Data from concurrent studies were provided by Messrs. J. E. Sceva and W. S. Bartholomew. Water samples were analyzed for bacteriological quality by the Public Health Laboratory of the Oregon State Board of Health. Preliminary barometric data were furnished by the U.S. Department of Commerce office at Salem Airport. The friendly cooperation of all is gratefully acknowledged.

WELL-NUMBERING SYSTEM

Wells discussed in this report are designated by symbols that indicate their location according to the rectangular system of land division. In the symbol 8/3W–3M1, for example, the part preceding the hyphen indicates respectively the township and range (T. 8 S., R. 3 W.) south and west of the Willamette base line and meridian. Because most of the State lies south of the Willamette base line and east of the Willamette meridian, the letters indicating the directions south and east are omitted, but the letters "W" and "N" are included for wells lying

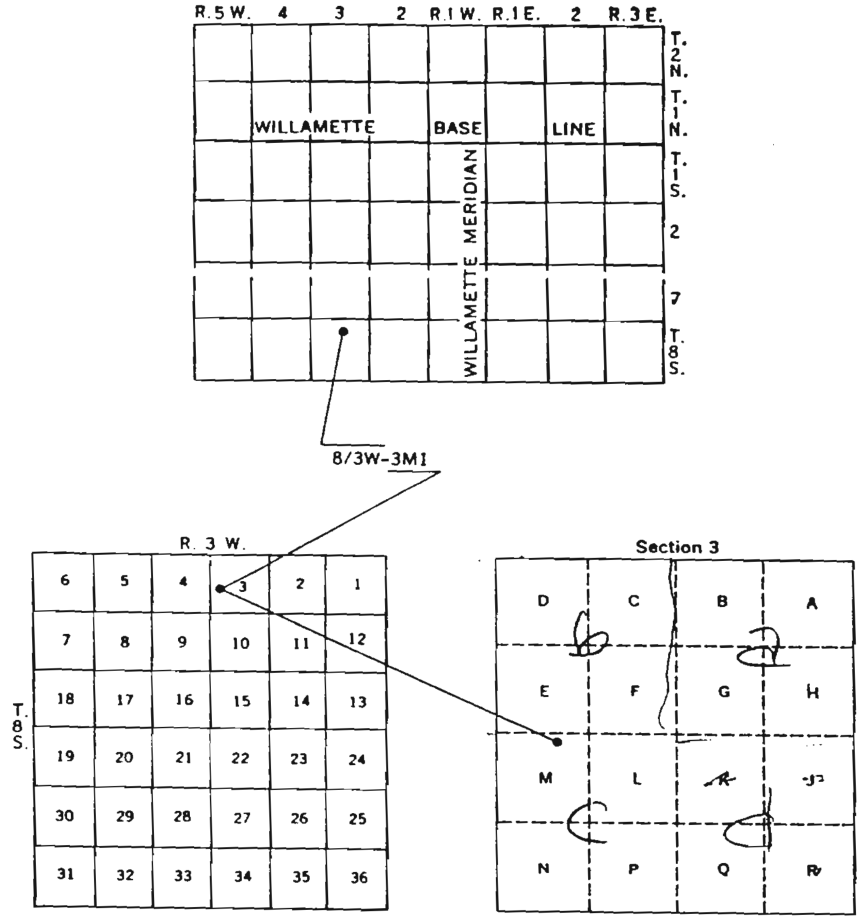

FIGURE 2.—Well-numbering system.

west of the meridian and north of the base line. The first number after the hyphen indicates the section (sec. 3), and the letter (M) indicates a 40-acre subdivision of the section as shown in figure 2. The final digit is the serial number of the well within that 40-acre tract. Thus, well 8/3W-3M1 is in the NW¼SW¼ sec. 3, T. 8 S., R. 3 W., and is the first well in the tract to be listed.

To relate the well numbers to the local designations for the wells, both the well number and the local designation (as Park well 2) are given in the first few references to each well.

THE HYDROLOGIC SYSTEM AND GEOLOGIC CONTROLS

Any successful artificial-recharge operation, especially one involving injection through wells, must function compatibly with the local

hydrologic system, which in turn is controlled largely by the geologic conditions. Therefore, an understanding of the hydrologic system and its geologic framework is essential for adequate design, operation, and evaluation of subsurface-injection operations. In the Salem Heights area, the preexisting information on local conditions was not sufficiently detailed and thus was augmented by considerable field mapping and interpretation of well records during this study.

The part of the hydrologic system that is most pertinent to this study is the ground water in the basalt rock that caps the Salem Hills. Therefore, that rock unit and its function as a ground-water reservoir were major subjects of the present study.

CHARACTER AND EXTENT OF THE BASALT

The basalt that supplies water to the wells in the Salem Heights area is part of the Columbia River Group (Stayton Lavas of Thayer, 1939, p. 7). This basalt forms the Salem Hills as well as other similar uplands to the northeast, east, and southeast; it also extends northward beneath the alluvial plain on which the city of Salem is built. The basalt of this area consists of remnants of a huge series of lava outpourings that extended through much of the Pacific Northwest during Miocene time. Most of the basalt rock that resulted from this volcanic activity is east of the Cascade Range, and Thayer (1939, p. 8) considered the remnants in this area to be near the western margin of that vast lava sequence.

The basalt of the Salem Hills consists of several individual flow layers, each probably thicker than 10 feet and some probably thicker than 100 feet locally. The total thickness of basalt in the Salem Hills varies considerably—the basalt is probably more than 500 feet thick in the vicinity of Prospect Hill (pl. 1) and less than 100 feet thick where it is penetrated in some wells in Salem.

The basalt is underlain by marine sedimentary rocks of Oligocene age. These rocks consist mostly of tuffaceous siltstone and sandstone, which are readily recognized by their characteristic tan, gray, and buff colors. The marine sedimentary rocks in this area are mostly saturated, but they are poorly permeable.

Prior to the outpouring of the basalt, the upper surface of the marine sedimentary rocks had been eroded into a rolling landscape which had a local relief of more than 400 feet. The earliest lava flows occupied the lowest parts of the prebasalt surface. Each later extrusion of lava inundated the previous flow layer as well as a higher and more extensive part of the prebasalt landscape. The differences in the thickness and the number of flow layers of the basalt in the area are due mostly to the irregularities in the prebasalt land surface.

The basalt flow layers, which were virtually flat before cooling, have been tilted along with underlying rocks by regional earth movements, and locally have been involved in landslides and slumping. The basalt now has a general northeast dip of 10° or less. Section *A–A′* (pl. 1) shows the relationship of the basalt and the underlying marine sedimentary rocks along a line approximating the general direction of dip.

The in-place basalt that forms the Salem Hills terminates on the west and south at steep slopes and bluffs overlooking an extensive band of landslide debris made up of the basalt and the underlying marine sedimentary rocks. On the northwest side of the Salem Hills, an area of about 2½ square miles that includes Croisan Ridge and Plank Hill apparently has slumped and perhaps tilted to the northwest along a curved fault of relatively small displacement (pl. 1). The structural conditions in the Salem Hills—the cuestalike abrupt western and southern sides and gentle northeast dip to the lower plain—are duplicated in the Eola Hills across the Willamette River to the northwest.

The basalt in individual flows is generally dense and impermeable. Near the upper and lower surfaces of flows, however, the basalt commonly is rubbly, scoriaceous, and vesicular. These rubbly zones associated with the contacts between individual flow layers are termed "interflow zones" (Price, 1967b, p. 18; Hampton, 1970). Columnar jointing, characteristic of the basalt in many other areas, is not common nor well developed in the Salem Heights area. In the bluffs along the west side of the area, where the best exposures of the basalt occur, joints are not abundant, and those observed tend to delineate irregularly shaped massive blocks rather than prismatic columns.

The upper part of the basalt has been deeply weathered and moderately eroded since its extrusion. It has weathered to a reddish-brown saprolitic soil, commonly as thick as several tens of feet. In many places the soil contains isloated less-weathered remnants of cobble and boulder size which can still be identified as basalt rock. The deep residual soil has contributed to the rounded, rolling configuration into which the upland has been eroded.

OCCURRENCE OF WATER IN THE BASALT

Water occurs in the basalt chiefly in cooling-contraction joints within the flow layers and in the porous interflow zones. Although the few exposures of relatively unweathered basalt in the area exhibit some jointing, these and other water-bearing features of the local basalt sequence must be assessed largely from the data on local wells (including those listed in tables 2 and 3) and from hydrologic studies in other areas underlain by basalt of the Columbia River Group (Foxworthy, 1962, p. 14, 15, 38; Hart and Newcomb, 1965, p. 17, 33–35; Price, 1967b, p. 18).

Because most of the observed joints appear to be tightly closed, they probably can transmit water vertically across flow layers only at a very slow rate even where hydraulic gradients are steep. Near the margins of the in-place basalt, where incipient slumping is common, joints may be more abundant and open. Such joint systems, if they occur, probably constitute the main conduits through which water moves from the soil zone into the deeper aquifers; however, no direct evidence of such open joints was found during this study.

Appreciable flow of ground water to wells and springs is principally through permeable zones at and near the contacts between certain flow layers. In the basalt of this region, such permeable interflow zones are characteristically discontinuous and of small extent, and their occurrence in any location or at any horizon generally is unpredictable. Therefore, the chances that a well will tap a productive water-bearing zone improve as more flow layers are penetrated.

Water-bearing interflow zones in the basalt are permeable because of one or a combination of several geologic processes. The upper part of most flows commonly contains abundant gas bubbles, or vesicles, which give the rock a spongy appearance and relatively great porosity. Even in flows where the vesicles are poorly connected, the vesicular zones may contribute to the permeability of the rock, especially if they were subjected to fracturing by earth movements or to weathering before inundation by a subsequent flow. Permeability also may result from the incomplete closure of one flow over surface irregularities in the flow below it. In some flow layers the permeability may be principally in the lower part of the flow, above the contact. For example, highly permeable zones may exist as a result of lava flowing into a pond or marsh. The steam that resulted from such occurrences altered and tended to inflate the lava and thus contributed to the permeability of the resultant rock materials.

Ground water exists in the basalt under three conditions of occurrence—unconfined, confined, and perched. Although the present study is concerned mainly with the artificial recharge of a deep confined aquifer, the movement to and character of water in that confined aquifer is inseparably related to the shallow unconfined and the perched ground water.

The upper surface of the unconfined ground water (the water table) in the area is indicated by the static (nonpumping) water levels in the shallowest wells. Below the shallowest saturated zone, however, ground water at most places in the basalt is confined to some degree by less permeable rock layers. All the wells of moderate to large yield in the area are believed to tap one or more confined zones in the basalt—that is, permeable interflow zones that are confined by the dense central parts of the enclosing flow layers, or basal zones in the basalt sequence that are confined between the underlying marine sedimentary rocks and overlying denser basalt. The imaginary surface that coincides with levels to which confined water rises in these wells is called the potentiometric surface. (See fig. 4.)

Ground water that was truly perched—underlain by an unsaturated zone—probably did not exist in the Salem Heights area under natural (predevelopment) conditions. However, perching probably has developed locally where some permeable interflow zones, in the upper part of the basalt sequence but below the water table, have become unsaturated by continuous drainage to deeper zones through the unlined parts of the deeper wells. (See fig. 3.)

THE MAIN CONFINED AQUIFER

The large-yield wells in the area, including the recharge well and most of the observation wells used in this study, are believed to tap the same highly permeable confined zone, of irregular thickness and limited extent, in the lower part of the basalt sequence. This zone yields as much as 1,000 gpm of water to wells that have specific capacities as great as 11 gpm per foot or greater. (See table 2.) In contrast, most of the wells in this area that tap basalt zones that are not part of the main confined aquifer produce less than 200 gpm and have specific capacities of about 2 gpm per foot or less.

This main confined aquifer lies mostly below the 100-foot altitude, and it has been found only in coincidence with the basinlike depression in the marine sedimentary rocks in secs. 9 and 10, T. 8 S., R. 3 W. Drillers' logs of wells indicate that the main aquifer may range in thickness from less than 10 feet to more than 100 feet. At most of those wells, the most productive zone in the main aquifer reportedly is not at the base of the basalt sequence but is about 20 to more than 50 feet above it.

Terms such as "carbonated," "eroded," "calcified," and "cinders" were used by the drillers to describe materials in the main aquifer. (See table 3.) Fragments of what probably are some of the materials so described were pumped from the recharge well during this study and were examined by the writer. The material was a tan to orange mixture of mostly sand-size particles (medium to coarse) composed of obsidian (volcanic glass), various secondary siliceous minerals, and palagonite (hydrated volcanic glass). Such an assemblage of minerals commonly results where molten lava of the Columbia River Group poured out into water or onto a surface that was marshy or very wet. The fact that it contains these palagonitic materials and that its known occurrence coincides with the central part of a preexisting land-surface depression—within and near the 100-foot contour on that depression (pl. 1)—strongly suggests that the main aquifer was formed by lava flowing into a marsh or pond that occupied that ancient basin. If so, there probably are not sizable extensions of the main aquifer beyond the area already defined by the wells that tap it.

GROUND-WATER RECHARGE AND MOVEMENT

Natural recharge to the basalt aquifers of the Salem Hills is derived entirely from local precipitation. A major part of the precipitation infiltrates the soil and weathered rock, but only a small fraction of this water percolates downward to the zone of saturation. Under natural (predevelopment) conditions, however, this small fraction was enough to maintain the water table at shallow depths beneath much of the Salem Hills.

From the upper part of the zone of saturation the ground water moves slowly downward to zones of progressively lower hydraulic head and toward wells or points of natural discharge. The water in the basalt follows a tortuous path, in some places flowing along the interflow zones and in others migrating across the flow layers. The water discharges naturally from the basalt, mainly through seeps and minor springs along the bluffs and canyons where the rock is exposed and by seepage into the other rock materials, notably the adjacent alluvial and lacustrine deposits and the landslide debris.

Under natural conditions, ground water did not discharge directly from the main aquifer. Water entered the unusually permeable aquifer by seepage from adjacent and overlying parts of the basalt sequence and left it, without much change in hydraulic head, by slow percolation northward, mostly through the basalt that dips beneath the city of Salem. The main route of the northward-moving ground water probably was through basalt that occupies an apparent northeast-trending trough or channel in the prebasalt land surface. (See pl. 1.) This channel-filling basalt doubtless is more permeable to laterally moving ground water than are the underlying marine sedimentary rocks; however it is less permeable than the main confined aquifer and therefore may be incapable of yielding large quantities of water to wells. This fact is suggested by the low yield of well 8/3W-3M1 (Madrona well), which completely penetrates the basalt in or near the middle part of the prebasalt channel (tables 2, 3). In other words, no evidence is available to indicate that a highly permeable extension of the main confined aquifer exists along this channel in the underlying rock.

Even though the main aquifer and the basalt that extends northward from it reach depths below the Willamette River and locally below sea level, the hydraulic heads of the confined water in the basalt are sufficient to raise the water to the level of the Willamette, which is the hydraulic "base level" for the region. Under natural (predevelopment) conditions, most of the ground-water discharge from the lower parts of the basalt in the area was by seepage to the alluvial and lacustrine deposits and landslide debris. In turn, water was discharged from those deposits by seepage to the Willamette River and the smaller streams, by evapotranspiration, and by spring flow.

During this study and for at least a few years preceding it, discharge of water from the main aquifer was principally by withdrawal from wells. The artesian heads have been lowered as much as several tens of feet by pumping (table 2), and as a result, subsurface migration of ground water from the main aquifer has greatly diminished.

Under present conditions, the main aquifer doubtless receives some inflowing ground water from higher parts of the basalt beyond the limited area of the main aquifer. The full extent of the recharge area for the main aquifer is not known, but the area probably includes some of the higher hills to the south and west. It is hydraulically impossible, however, that any natural recharge for the main aquifer is originating beyond the Salem Hills, and the actual recharge area probably constitutes only a fraction of that upland region.

In general, the hydraulic heads in the basalt sequence decrease progressively from the upper to the lower zones. This vertical difference in heads was large even under predevolpment conditions; it reportedly was about 235 feet between the water table and the main confined aquifer at well 8/3W-9K1 (United Growers, Inc.) in 1947. This head difference provides the energy of position to move the ground water downward across the poorly permeable layers in the basalt sequence. The natural vertical head difference has been increased by the lowering of heads in the main aquifer by pumping. Consequently, the downward percolation of shallower ground water into the main aquifer has been substantially increased during recent years.

The development of ground-water supplies from the main confined aquifer has also increased the recharge to that aquifer in another way. The slow natural percolation of ground water from higher to lower parts of the basalt sequence has been short circuited locally by unlined wells. Most of the drilled wells that tap the basalt have casings that extend only through the upper part of the hole—commonly into the first solid layer of rock. As shown by figure 3, the higher water-bearing zones in the unlined interval can drain, more or

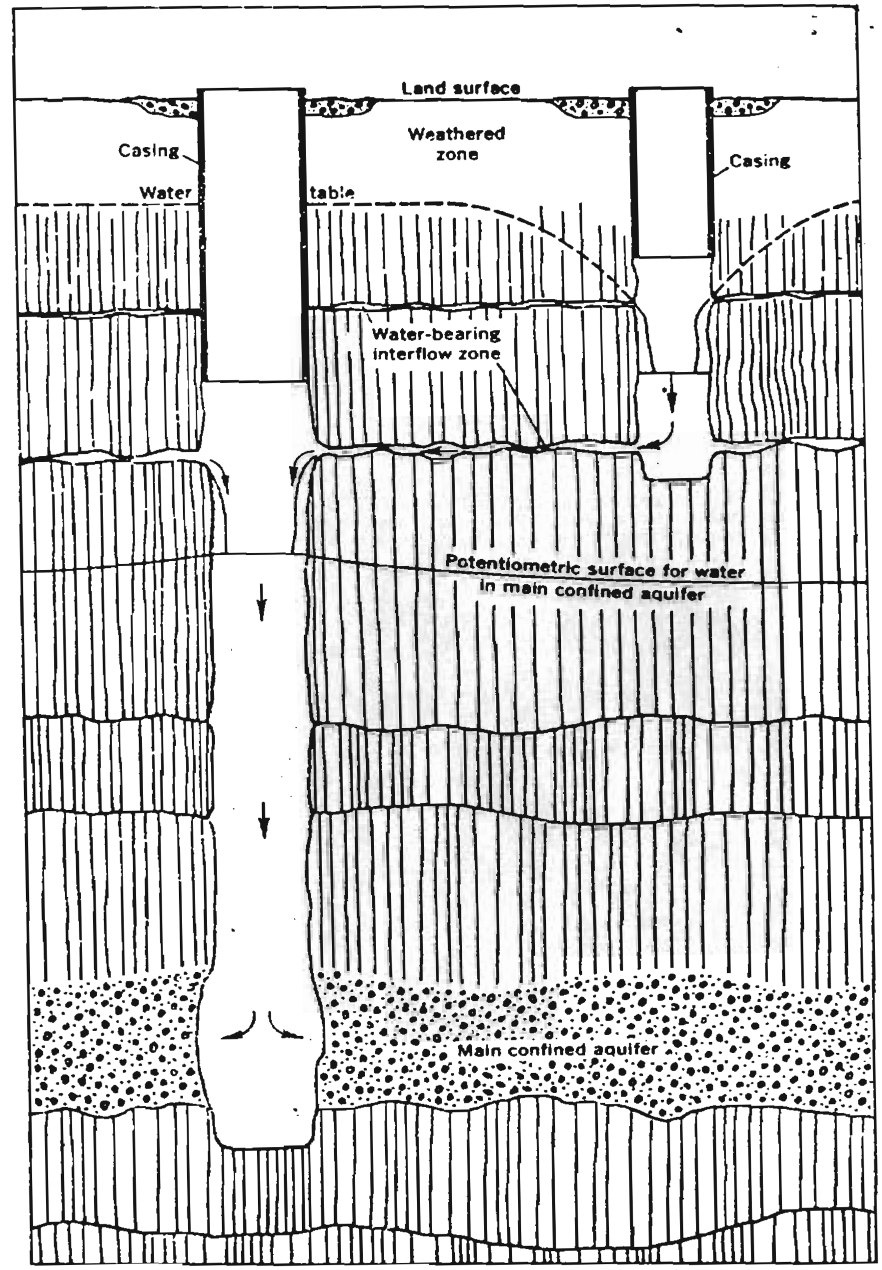

FIGURE 3.—Diagrammatic section showing downward migration of ground water through unlined parts of wells that tap the basalt.

less continuously, through the well bore to the zone having the lowest hydraulic head. In the wells that tap the main aquifer, wherin heads are generally lower than those in any other parts of the local basalt sequence, the main aquifer can receive recharge for any of the higher water-bearing zones that are not blocked off by the casing. Not only does this drainage through the unlined wells augment the recharge to the main aquifer, it also has important water-quality implications. It constitutes a route to the main aquifer for oxygen-rich water, discussed subsequently, and for any contamination that may be present in the higher water-bearing zones.

WATER-LEVEL FLUCTUATIONS

Despite the aforementioned increased recharge to the main aquifer and the decrease in natural discharge related to the increased pumping, the water levels in wells that tap the main confined aquifer have been declining progressively from year to year during at least the last few years prior to this study. Water-level data furnished by the Oregon State Engineer indicate that the level in well 8/3W–3M1 (Madrona well) declined about 17 feet from May 1958 to May 1961. Actually, the progressive decline of artesian heads in the main aquifer probably began at least as early as 1954, when well 8/3W–10K2 (Park well 1) began operation. In well 8/3W–9K1 (cannery well), which was the first well in the area to tap the main aquifer, the level declined about 38 feet, from about 275 feet to 313.4 feet below land surface, in the period February 1947 to February 1962 (table 2). Virtually all that decline was caused by the increased pumping from the main aquifer during that period.

Fluctuations of hydraulic head in the main confined aquifer, which probably amounted to only a few feet per year under natural conditions, have been increased substantially by pumping. Water levels in wells that tap the main confined aquifer usually are highest in spring, when the greatest recharge from precipitation and snowmelt can be expected. The levels usually are lowest in late summer or early autumn, when there is little precipitation and withdrawals from wells are greatest. However, water-level measurements made during February–November 1962 indicated that, during that year, the highest water levels in several of the wells occurred during the last half of July or the first part of August (pl. 2). Measurements for this study had not yet begun during the period of lowest ground-water levels in 1961, which occurred in August of that year.

Short-term fluctuations, resulting from different causes, are superimposed on the seasonal fluctuations of the potentiometric surface. Included are fluctuations in response to changes in atmospheric pressure, water-level declines caused by intermittent pumping of wells tapping the main aquifer, and rises in water level resulting from the artificial-recharge tests. Water levels in each of the more productive wells tapping the main aquifer generally respond fairly rapidly to pumping by other wells, even those a considerable distance away. Such rapid and widespread response to changing pressure is characteristic of confined aquifers.

SOURCE AND TREATMENT OF THE RECHARGE WATER

The water that was experimentally injected during this study was chlorinated and fluoridated water from the Salem municipal-supply system. The water is from infiltration galleries (lateral wells) on Stayton Island in the North Santiam River about 17 miles southeast of Salem and just upstream from the town of Stayton (not shown on pl. 1). Upon withdrawal from the galleries, the water is treated with chlorine gas and then flows about 10 miles through a pipeline to Franzen Reservoir in the village of Turner (not shown), where it is again chlorinated to maintain a chlorine residual of about 0.2 mg/l (milligrams per liter). From Turner a pipeline carries the water the remaining distance to Salem.

The water from the Stayton Island galleries constitutes the entire normal supply for the city of Salem. The capacity of the system is 75 mgd (million gallons per day), and the city's water right on the North Santiam River allows an average withdrawal of 85.3 mgd. The average output of the Salem system in 1962, including the water supplied to the Salem Heights Water District, was about 8 mgd.

The recharge water was taken from the city's main pipeline where it passes near a booster-pump station that was built by the Salem Heights Water District near the center of sec. 2, T. 8 S., R. 3 W. (pl. 1). At the pumping station, fluoride was added to produce a fluoride-ion concentration of about 1–2 mg/l in the water, and the water was then pumped toward a storage reservoir for the Salem Heights distribution system.

The recharge water was diverted from the pipeline between the booster-pump station and the local storage reservoir where the pipeline passed near the wellhouse of the recharge well (fig. 5). The water withdrawn from the recharge well was also pumped through the same pipeline to the reservoir. None of the recharge water passed through the local reservoir before it was injected.

METHODS OF STUDY AND EQUIPMENT

In general, the methods and procedures used in this study were patterned closely after those used in the previous artificial-recharge study at The Dalles (Foxworthy and Bryant, 1967, p. 13). Because the depleted aquifer is a deep confined zone whose recharge area is not known precisely, the only method of artificial recharge that was considered was direct injection of water through wells that tap the aquifer. The injection was accomplished during three separate test periods, each longer than the preceding, with the recharge water being injected through the existing turbine pump in one of the water district's supply wells. Each period of recharge was followed by at least one pumping test to determine the effect of the recharge on the capacity of the well and on the character of the water in the vicinity of the well. Water levels in observation wells in the area were measured during the recharge and pumping tests and periodically throughout the period of investigation. As in The Dalles study, the actual recharge experiments were preceded by preliminary tests and evaluation (a) to determine prerecharge conditions, (b) to foresee possible problems, and (c) to guide the injection experiments.

PRELIMINARY EVALUATION

The preliminary evaluation included consideration of several physical and engineering factors that have constituted actual or potential problems in previous subsurface-injection operations:

1. Adequacy of the supply of recharge water.
2. Permeability and storage capacity of the aquifer.
3. Clogging of the well and the aquifer materials.
4. Temperature changes of the water in the recharged aquifer.
5. Recovery of the injected water from subsurface storage.
6. Suitability of the recovered water for the intended use.

Some of these factors can be evaluated by methods now available; others are more difficult to determine. Even under the most favorable conditions, and where the chemical and physical characteristics of both the native ground water and the recharge water are known reasonably well, it is often impossible to predict reliably how a subsurface-injection operation will function on a sustained basis. The risk to expensive wells and equipment is lessened if long-term subsurface injection is approached through a series of progressive, carefully evaluated injection experiments.

The preliminary evaluation necessitated the collection and interpretation of additional data as well as review of data then existing. Selected preliminary data are presented with the experimental data in the tables of this report.

The chemical and sanitary quality of the water from the Salem municipal system were evaluated in consultation with Mr. L. B. Laird, former district chemist of the Geological Survey for thePacific Northwest, and Mr. E. J. Weathersbee, district sanitary engineer for the Oregon State Board of Health. (See section on "Clogging.")

ADEQUACY OF SUPPLY OF RECHARGE WATER

Water in excess of demands within the city of Salem is available from the city system except during periods of maintenance and brief periods of peak demand which usually occur during July or August. Both the capacity of the system and the water right to withdraw the water from the Stayton Island galleries greatly exceed the average needs of the city (p. F15). Therefore, supplies of high-quality water were ample in quantity for the planned recharge experiments and also, apparently, are ample for a long-term program of artificial recharge through wells, if such a program is judged to be feasible.

STORAGE CAPACITY AND PERMEABILITY OF THE AQUIFER

The thickness and extent of the aquifer materials, as determined from the records of wells (tables 2 and 33), and the major fluctuations of water levels (p. F14) indicate that the aquifer is capable of storing and releasing large volumes of ground water—certainly more water than would be involved in any foreseeable program of subsurface injection.

One of the most fundamental requirements for successful subsurface injection is that the aquifer be at least moderately permeable and preferably highly permeable. Not only does the aquifer permeability largely govern the energy required to inject water at a given rate, but it also controls the resultant buildup of hydraulic head and the spread of the recharge water outward from the injection well. The large yields of the wells that tap the main aquifer of the Salem Heights area indicate that the aquifer is at least moderately permeable. During the preliminary phases of this investigation, additional information was collected on the water-yielding character of the main aquifer in the vicinity of the recharge well.

On February 28, 1962, a prerecharge pumping and recovery test was made at the recharge well. The main purposes of this test were to check the response of the observation wells (p. F25) and to obtain prerecharge data on the yield characteristics of the recharge well and the adjacent aquifer for later comparison with similar data from tests following each of the recharge experiments (table 1). In addition, water samples obtained during the prerecharge test were used to determine the chemical, physical, and bacteriological character of the native ground water.

During the prerecharge pumping test, an average of 669 gpm was pumped from the well for 5 hours; the resultant drawdown of water level in the well was 46.8 feet (table 1). The specific capacity was 14.3 gpm per foot of drawdown. If it is assumed that specific capacity during injection through a well (injection rate divided by water-level buildup) is approximately equivalent to the specific capacity during pumping, the above value suggests that a water-level buildup of 1 foot in the well would move water into the aquifer at a rate of about 14 gpm. Thus, about 7 feet of water-level buildup in the well might be expected for an injection rate of 100 gpm, 14 feet of buildup for 200 gpm, and so on. Because the static (nondischarging) water level in the recharge well was about 236 feet below land surface at the time of the prerecharge tests, the well obviously could readily accommodate the planned injection of several hundred gallons per minute unless severe clogging occurred.

WATER TEMPERATURES

Subsurface injection of recharge water having a temperature markedly different from that of the native ground water can cause enough temperature change to limit the usefulness of the receiving ground water for some purposes (Brashears, 1941, p. 817; Brown, 1963, p. 19). Also, the temperature of the water in the aquifer determines the viscosity of the water, which in turn affects the apparent permeability (Sniegocki, 1960, p. 1490). At The Dalles, the specific capacity of the recharge well was temporarily reduced substantially following injection with water as much as 13°C (23°F) colder than the native ground water (p. F4). Therefore, in the Salem Heights study, the possible effects of any difference in the temperatures of the recharge water and the native ground water were evaluated on October 30, 1961, beginning with a comparison of the temperatures of the Salem public-supply water and the recharge-well water (table 4). The temperature difference was only 1°C (2°F) at that time. Because of that small difference and because any large temperature fluctuations in the city water at the Franzen Reservoir were expected to be moderated by the subsequent long transmission underground, the possible effects of temperature differences during the recharge experiments were expected to be small.

CLOGGING

Clogging of the recharge well or the adjacent aquifer materials is almost universally experienced to some degree in recharge through wells. In various subsurface-injection operations, including previous operations in Oregon and Washington (Price and others, 1965), clogging has been attributed to (a) sediment in the recharge water, (b) chemical reactions in the aquifer, (c) growth of organisms in the well or aquifer, and (d) air in the recharge water.

SEDIMENT

Preliminary samples of the Salem public-supply water, collected after the water passed through the booster-pump station and the pipeline adjacent to the recharge well, contained sediment in concentrations of 0.3 mg/l (table 5, samples for March 2). This low concentration was reported to be typical of the sediment content of the Salem public-supply water. Therefore, the sediment in the recharge water was not expected to be a significant clogging agent, even during extended periods of injection, unless the sediment content were to increase markedly.

CHEMICAL REACTIONS

Chemical reactions of a recharge water with a native ground water or with aquifer materials can cause clogging by ion exchange or the formation of chemical precipitates.

Undesirable chemical precipitation may be caused by the different chemical and physical characteristics of the waters mixed during subsurface injection. Even small changes in pH, Eh (reduction-oxidation potential), temperature, pressure, and concentration of some dissolved gases (such as air) can cause the precipitation of chemical constituents such as iron, aluminum, calcium carbonate, and silica. For example, ground water commonly contains some dissolved iron that is in the ferrous, or lower oxidation, state. If water containing ferrous iron is mixed with oxygen-rich water or is exposed to oxygen in the atmosphere, much of the iron is oxidized to the ferric state and precipitates in the form of ferric hydroxide, which is virtually insoluble at normal pH values of ground water (Hem, 1959, p. 60). Likewise, if ground water that contains abundant silica in the ionic state is cooled, as by cold recharge water, some of the silica may precipitate (Siever, 1962, p. 128–134). When this chemical precipitation is substantial, aquifer permeabilities may be greatly reduced.

The preliminary analyses of the Salem city water and the native ground water showed that concentrations of the chemical constituents that might enter into precipitating reactions were very low and that the two waters were very similar in their chemical and physical characteristics. Therefore, the danger of incurring unwanted precipitation was considered to be slight. Also, the continued high performance of the recharge well, in spite of long-term inflow of oxygen-rich water during nonpumping periods (p. F14), was considered to be proof that oxidizing reactions within the aquifer would not be troublesome.

Of many chemical reactions that might occur when an outside water is added to an aquifer environment, one that has been considered to be a potential cause of clogging is an ion-exchange reaction involving certain clay minerals (Sniegocki, 1963a, p. 12). Some clays, when exposed to a water with a high sodium-ion content, tend to release calcium or other ions and adsorb the sodium ions. As a result, the clays swell in volume or are dispersed in a semicolloidal suspension. Either result may decrease the permeability of an aquifer and, therefore, must be evaluated as a potential problem in subsurface injection. Calcium clays of the montmorillonite group are most likely to react in this way.

Neither the swelling nor the dispersal of clay, however, was considered to be a potential problem in the Salem Heights tests. The palagonite zones in the principal aquifer may contain some calcium clays (from alteration of plagioclase in the original volcanic glass) which might tend to swell or to disperse upon reaction with sodium ions. Neither the sodium in the recharge water nor the clay, however, was thought to be abundant enough to cause a noticeable effect on the aquifer permeability.

ORGANISMS

Certain organisms can be troublesome if they are injected underground. Pathogenic bacteria, of course, can render a ground-water body unfit as a source of drinking water. However, other organisms, the so-called nuisance bacteria, although not disease producing in humans, are also undesirable because they may color the water, cause unpleasant taste and odor, or produce slimes or other products that clog recharge wells and aquifers.

The Salem city water supply is chlorinated at both the withdrawal works and the Franzen Reservoir and so is considered to be effectively free of pathogenic organisms when it reaches the booster-pump station. Before the injection tests, the existence of nuisance bacteria was tested in a series of samples of (a) chlorinated water from the booster-pump station and (b) water pumped from the injection well. The samples were tested by the public health laboratory of the Oregon State Board of Health. Laboratory cultures of the samples failed to reveal any nuisance bacteria in the waters. Therefore, no problem of water deterioration nor of clogging of the aquifer or recharge well was anticipated as a result of nuisance bacteria.

AIR

Air that is introduced into a well during artificial recharge not only can cause clogging by producing the chemical reactions mentioned previously, but also can reduce the permeability of the aquifer by physically blocking the pore spaces with bubbles. Even a relatively small volume of air in an aquifer may markedly reduce its permeability by blocking the main routes of water movement through the aquifer (Orlob and Radhakrishna, 1958, p. 648). Such bubbles normally are tightly held to the aquifer materials by molecular attraction, and high velocities are required to displace them. Furthermore, air occurring as bubbles in an aquifer can dissolve only very slowly, even in water that has a very low dissolved-air content.

Air bubbles have been cited as a cause of significant clogging during previous experimental injection into basalt aquifers and, therefore, were considered to be a potential problem in the present study. During the tests at Walla Walla, Wash., air bubbles probably were formed by air coming out of solution and also by entrainment of air as the recharge water was allowed to cascade down inside the pump column (Price, 1961, p. 17). In the tests at The Dalles, Oreg., the water was injected under pressures sufficient to prevent air entrainment, but troublesome bubbles apparently formed from air coming out of solution at points of sharp pressure drop within the piping system that carried the recharge water to the well (Foxworthy and Bryant, 1967, p. 19, 36).

Air dissolved in water in a state of equilibrium is released from solution if the water becomes warmer or if the pressure on the water decreases. Conversely, if the water becomes cooler or if the pressure increases, the air will remain in solution, and even more air can be dissolved. Pressure changes affect the solubility of air more than do changes in temperature. The Salem Heights tests were designed to have the water coming to the well under pressure considerably greater than atmospheric pressure to prevent air entrainment and to help keep any dissolved air or other gases in solution in the recharge water. Because of this design and because no large difference was expected between the temperatures of the recharge water and of the native ground water, it was assumed that any dissolved gas would tend to remain in solution once it reached the aquifer and came under the relatively great hydrostatic pressures there. Piping to the well was designed to minimize the expected problem of air coming out of solution in the pipeline carrying the recharge water. (See section on "Recharge well and accessory equipment.") Also, to facilitate the the removal of the air bubbles that were anticipated, or of any other clogging agents, periodic pumping and redevelopment of the recharge well were planned.

RECOVERY OF INJECTED WATER

One of the most important questions in assessing the feasibility of any subsurface-storage operation is, "Will enough of the injected water be economically recoverable?" Obviously, an adequate quantitative answer to this question could only be obtained by experiment. A preliminary qualitative evaluation, however, was needed to guide the experiments.

As a mound of pressure builds up around a recharge well during injection, water moves outward from the well through the aquifer. The water continues to move away from the well not only during injection but also after injection has stopped—at least until an equilibrium is reestablished with the regional hydraulic gradient. The volume of injected water that is recoverable, therefore, depends not only on the volume injected and rate of injection but also on the preinjection conditions in the aquifer and the elapsed time between injection and withdrawal. The aquifer boundaries, as well as the relative locations of the points of injection and withdrawal, also are important considerations. Commonly, some of the injected water moves away from the recharge well far enough that it cannot be pumped back through that well and can only be recovered from wells located downgradient.

Preliminary water-level data for the deep wells, as well as water-level measurements made at the time of the prerecharge pumping test (February 28–29, 1962), were furnished by the office of the Oregon State Engineer. Those data showed that the potentiometric surface of the main confined aquifer contained a major closed cone of depression extending mostly west of the recharge well and centered around well 9J1 (fig. 4). The water-level data, plus the evidence of the limited extent of the main aquifer, strongly indicated that the water injected during the experiments would not escape rapidly from the aquifer. Furthermore, the data indicated that although the recharge water might pass beyond the area of influence of the recharge well, it would likely move in the general direction of the water district's well 9J1, which would be capable of intercepting most of the water.

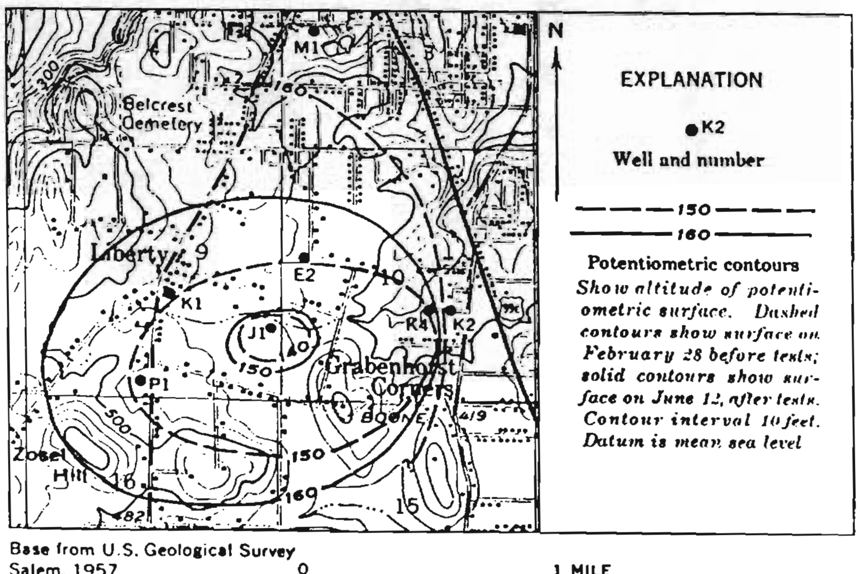

FIGURE 4.—Contours on the potentiometric surface of the main confined aquifer before and after artificial-recharge tests, 1962.

Information furnished to the Salem Heights Water District by Clark & Groff Engineers, Inc., indicated that the surplus water could be obtained from the city of Salem at a very favorable price during the 8-month period October–May. The price was such that, barring major difficulties with the injection operation, the surplus water could be injected through the water district's wells and subsequently pumped back from the ground-water reservoir at about half the cost for direct use of Salem water during June–September. Therefore, a subsurface-storage operaiton appeared to be economically beneficial if more than about 50 percent of the injected water could be recovered later.

SUITABILITY OF RECOVERED WATER

As both the recharge water and the native ground water were suitable for public-water supplies, they were expected to be suitable for that purpose after mixing. The preliminary analyses of samples collected on October 30, 1961 (table 4), indicated that both waters surpassed the chemical-quality standards for drinking water recommended by the U.S. Public Health Service (1962). Furthermore, no major temperature change and no deterioration of taste, color, odor, or bacteriological quality of the waters were foreseen as a result of the subsurface injection and later withdrawal.

RECHARGE WELL AND ACCESSORY EQUIPMENT

Well 8/3W–10K4 (Park well 2) was the recharge well and the pumped well in tests made during this investigation. It is at the end of Woodmansee Court (not marked on map), near the center of sec. 10, T. 8 S., R. 3 W. It discharges into an 8-inch supply line which carries the water to a surface reservoir at a level about 208 feet higher than the pump. Prior to the connection with the Salem system, well 10K4 was one of the main sources of supply for the Salem Heights district.

As shown in table 2, well 10K4 is 345 feet deep and is cased to a depth of 107 feet with 12-inch-diameter steel casing. The principal water-bearing zone is broken basalt and basaltic cinders in a zone 256–295 feet below land surface. The well is equipped with an 8-stage turbine pump driven by a 100-horsepower electric motor. Both the turbine bowls and pump column have nominal diameters of 8 inches. The intake to the pump is through a cone-shaped wire strainer and an 8-inch-diameter tailpipe, the opening of which was at a depth of 318 feet below land surface during this study. Discharge from the pump is through a 6-inch pipe which, 23 feet north of the well, joins the main

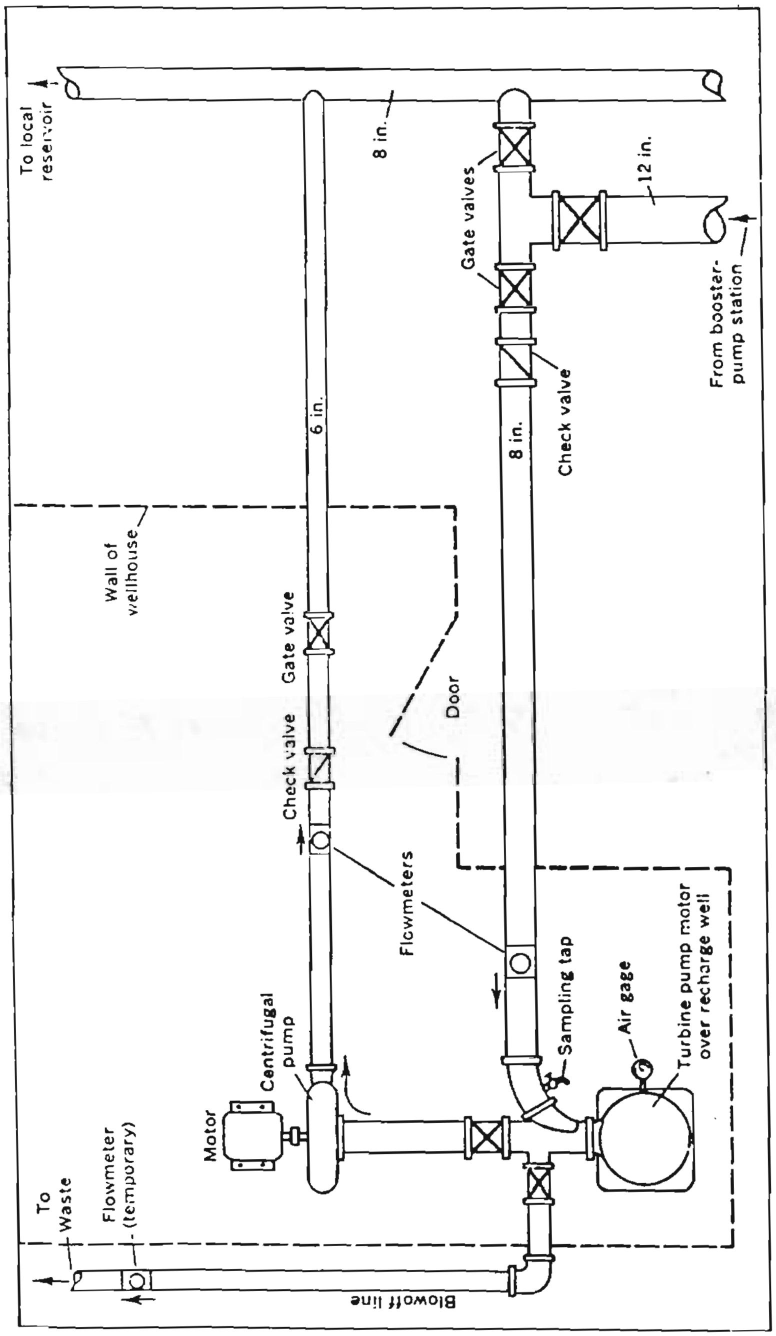

FIGURE 5.—Schematic diagram of piping and equipment at the recharge well, S/3W-10K4 (top view).

8-inch pipeline to the aforementioned surface reservoir. The discharge line is equipped with a totalizing watermeter, located in a pit within the wellhouse. Figure 5 is a schematic diagram of the equipment and water system in the vicinity of well 10K4.

A 12-inch pipeline, bringing Salem water from the booster-pump station, was extended to the well site and connected with the existing 8-inch line to the surface reservoir. The existing piping to the wellhouse was then modified to add a separate system of piping, valves, and a flowmeter to carry the recharge water to the well (fig. 5).

Although points of sharp increase in flow velocity and resultant pressure reduction could not be avoided throughout, large-radius bends were used in the short line from the 12-inch pipeline to the well wherever possible. This minimized the pressure drops and, therefore, the opportunity for dissolved air in the recharge water to come out of solution.

Modification of the piping at the well included the extension of an existing blowoff line from the pump to a nearby depression in the land surface. The blowoff line was used to discharge turbid water at the beginning of pumping tests and during redevolpment of the injection well. At such times, a portable flowmeter was attached at the end of the blowoff line to measure the discharge through that line.

OBSERVATION WELLS

During the tests, water levels were measured not only in the recharge well (10K4) but also in six other water-district wells (3H1, 3M1, 9J1, 9P1, 10E2, and 10K2) and in a well owned by United Growers (9K1). The descriptive records and drillers' logs of these wells are presented in tables 2 and 3, respectively. Water-level measurements from the wells are shown graphically on plate 2.

Levels in wells 10E2 and 3H1 were measured with a steel tape; wells 3M1 and 9P1 had semiautomatic water-level recorders installed. Measurements from those four wells are considered to be generally accurate to plus or minus 0.02 foot. Levels in wells 9J1, 9K1, and 10K4 were measured by existing air lines and pressure gages because equipment or conditions at those wells did not allow direct measurement. The air gages at those wells probably have a sensitivity no greater than about 0.1 foot of water. Well 10K2 was measured with an electrical sounding line, under very difficult conditions, and measurements in that well probably are accurate to within 0.5 foot. Wells 9J1, 10E2, and 10K2 were the most useful in assessing the effects of the artificial recharge.

Well 9J1 (Arlene well) is about 3,200 feet west-southwest of the recharge well and was about at the center of the cone of depression in the potentiometric surface of the main confined aquifer (fig. 4). It is 475 feet deep, is unlined by casing below the 82-foot depth, and penetrates the thickest part of the main confined aquifer (at least 93 ft thick). It reportedly has yielded as much as 600 gpm, and was one of the water district's most productive wells. It showed a clear response to the injection and pumping at well 10K4 and also responded to the pumping at well 9K1 (pl. 2).

Well 10E2 (Fir Dell well) is about 2,700 feet west-northwest of the injection well and 2,000 feet north of well 9J1. It was drilled deeper than any other water district well (617 ft) and has the deepest casing (448 ft). Because its casing extended below its range of water levels (table 2), well 10E2 did not have the usual cascading water inside the well bore (fig. 3); therefore, its water levels could be measured by the wetted-tape method and probably are more accurate than those obtained from the other deep observation wells. The fluctuations of water level in the well responded quickly and smoothly to recharge and pumping at well 10K4.

The other observation wells responded little or not at all to the recharge and pumping tests at well 10K4, but provided useful background and control data. Well 3H1 (Butler well) does not tap the main confined aquifer and is north of the area of influence of the recharge and pumping tests. It was measured during the latter part of recharge test 2, during subsequent tests, and periodically for several months thereafter, to obtain data on the regional water-level fluctuations in the basalt aquifers not affected by the concentrated pumping.

Well 3M1 (Madrona well) apparently is in hydraulic connection with the northernmost part of the main confined aquifer. It reflects the general trends of fluctuations in that aquifer and has been used as a long-term observation well by the Oregon State Engineer. However, it showed very little response to the recharge or pumping tests made during this study. This well probably taps less permeable basalt which filled the prebasalt channel previously described (p. 11).

Well 9P1 (Steinke well), which may be near the western edge of the main confined aquifer, also was useful for an indication of general seasonal trends of heads in the main confined aquifer. This well responded only slightly to the first two recharge tests and associated pumping tests; any possible response to later tests was completely masked by pumping at well 9K1.

Well 10K2 (Park well 1) is 483 feet east of the injection well. It apparently penetrates only about 7 feet of permeable basalt in the main aquifer zone, which may have thinned in the interval between the two wells. Even though the wells are closely spaced, the hydraulic connection between them is not so good as was expected. The static water levels in well 10K2 consistently stood 15–25 feet higher in altitude than the levels in well 10K4, and had a net rise much greater than that in any of the other wells measured during this study (pl. 2). Furthermore, while the level in well 10K4 rose as much as 126 feet during recharge test 3, the maximum rise in well 10K2 was only about 5 feet—about twice as much as the rise in well 10E2, which is about 2,200 feet farther from the recharge well. The comparatively poor correlation of water levels in these wells may be due partly to incomplete penetration of the basalt by well 10K2. (See table 3.) Also, this observation well probably is near the edge of the main confined aquifer, where the aquifer is likely to be thinner and less permeable than it is elsewhere.

However, these discrepancies between nearby wells probably are mainly results of very erratic texture, hydraulic interconnection, and permeability of the aquifer materials. (See p. F10.)

Well 9K1, owned by United Growers, Inc., is about 5,300 feet west of the recharge well. It was the only observation well that was pumped during the period of this study—for testing and rehabilitation during April and May 1962 and for industrial use during July–October of that year (pl. 2). Pumping of well 9K1 during recharge test 3 caused measurable drawdown in well 9J1 (Arlene well) and 9P1 (Steinke well). Like well 10E2 (Fir Dell well), 9K1 has casing that extends to a considerable depth (431 ft) although the casing is perforated below the 290-foot depth.

EXPERIMENTAL PROCEDURES AND INSTRUMENTS

From March 20, to May 15, 1962, water from the Salem municipal water system was injected into well 10K4 (Park well 2) during three tests of about 1-, 5-, and 15-day durations. The first two recharge tests were made by personnel of the Geological Survey, and the last test was made largely by personnel of Salem Heights Water District. Each recharge test was followed by at least one pumping test, and the last two recharge tests were also followed by periods of surging to clean the injection well.

During the pumping tests and the first and second recharge tests, water samples were collected to determine chemical quality, dissolved oxygen, sediment content, and bacteriological quality. During the third period of recharge, samples were collected for partial chemical analysis and determination of sediment content only. During the pumping tests and the first recharge test, part of the test water was continuously passed through a conductivity cell that was connected to a conductivity bridge; this arrangement allowed instantaneous measurement of the temperature and specific conductance [1] of the water flowing into or out of the well.

[1] A measure of the capacity of the water to conduct electrical current, specific conductance varies with the concentration and degree of ionization of dissolved constituents and also with water temperature. It is expressed herein as micromhos per centimeter at 25°C.

The flow of water was measured during pumping by a totalizing flowmeter on the discharge line and during recharge by a combination totalizing flowmeter and rate meter on the injection line. The flow rates were determined periodically by comparison of the readings of the totalizing meters during timed intervals. The flow of recharge water to the well was adjusted slightly by means of the gate valves (fig. 5). Line-pressure readings at a gage on the injection line were made periodically as a rough check against variations in flow rate.

During all the tests a recording microbarograph was operated in the wellhouse to provide data for possible use in the determination of and adjustment for any significant water-level fluctuations caused by changes in barometric pressure.

Laboratory analyses of water samples, except those for bacteriological determinations, were made in the Geological Survey Laboratory at Portland, Oreg. The analyses were made by standard methods (Rainwater and Thatcher, 1960). The results of most of the complete and partial chemical analyses are presented in table 4, and sediment determinations are shown in table 5.

To accomplish the surging that was required to clean the well after the second and third recharge tests, the pump on the well was started and allowed to run for 45 seconds and then was shut off for 45 seconds. This procedure allowed a column of water to be lifted and about 800 gallons or more of water, carrying sediment and rock particles, to be discharged through the blowoff line (fig. 5); when the pump stopped, several hundred gallons of water surged down the pump column into the well and adjacent aquifer materials.

RECHARGE AND PUMPING TESTS

In the following discussion of the individual experiments, the recharge tests are designated by the numbers 1, 2, and 3. The pumping tests that followed each period of recharge are assigned corresponding numbers, with letter designations added for tests involving more than one pumping period. Significant data from the tests, as well as from the prerecharge pumping tests, are summarized in table 1.

During the first recharge test (March 20–21, 1962), about 24 hours in duration, 1.05 million gallons of water was injected at an average rate of 725 gpm. The maximum buildup of water level in the well was 70.6 feet above the prerecharge static level. Thus, the specific capacity (rate of injection divided by water-level buildup) was about 10.3 gpm per foot. Within about 2 hours after injection was stopped, the level in the well declined to a position 1 foot above the prerecharge static level, and pumping test 1 was begun.

Although the recharge water contained much more sediment than was expected (table 5), virtually all the sediment injected during recharge test 1 probably was removed from the well during the early part of the subsequent pumping test 1. During the pumping test, the sediment content 1½ minutes after pumping began was about 1,300 mg/l; but after 1½ hours the average sediment content was only 2 mg/l (table 5), and the concentration remained at a few milligrams per liter for the duration of the test. The specific capacity near the end of pumping tests 1 was about 14.7 gpm per foot, or about 0.4 gpm per foot greater than the specific capacity of the well during the prerecharge pumping test.

During recharge test 2, the injection was continued for 5 days (April 16–21); a total of 5.82 million gallons was injected into the well at an average rate of 821 gpm. The maximum buildup of water level in the well during this recharge test was about 107 feet, at which time the specific (recharge) capacity was about 7.7 gpm per foot, or roughly half the specific capacity during pumping test 1. After recharge test 2, the water level in the recharge well did not decline to its pretest static level but remained 2 feet above the pretest level 3 days after injection was stopped.

As in recharge test 1, the water injected during recharge test 2 carried significant amounts of sediment into the well, especially during the first 8 hours, and periodically thereafter. However, most of the sediment was removed during pumping test 2. Relatively large amounts of sediment were contained in the water pumped during most of that test (table 5).

Pumping test 2 was begun 3 days after recharge test 2 ended. Pumping was continued for 5 hours, during which a total of 185,000 gallons of water was withdrawn at an average rate of 617 gpm. The maximum drawdown was 47.9 feet, at which time the specific capacity was 12.9 gpm per foot, or about 88 percent of the specific capacity measured during pumping test 1. However, the specific capacity was improved, even beyond the prerecharge value of 14.3 gpm per foot, by surging the well for about 40 minutes. Data derived from pumping test 2A, which followed that surging, indicate a specific capacity of 17.8 gpm per foot near the end of this 2-hour test.

Recharge test 3 lasted nearly 15 days (May 1–15). During that period about 17.6 million gallons of water was injected at an average rate of 834 gpm. The maximum buildup of water level in the well, measured near the end of the recharge period, was about 126 feet, and the specific capacity then was about 6.6 gpm per foot. Except for the first part of this recharge test, the sediment content of the injection water was much less than that during recharge tests 1 and 2 (table 5). Furthermore, virtually all the injected sediment was removed from the well during about the first 1½ hours of pumping test 3. Recharge test 3 was stopped because of a sharply declining trend in the specific capacity of the recharge well (fig. 6) that was suspected of indicating serious clogging of the aquifer materials in the vicinity of the well. Fortunately, however, the specific capacity of the well was restored to above the prerecharge value during pumping test 3 and the surging that preceded pumping test 3A (table 1).

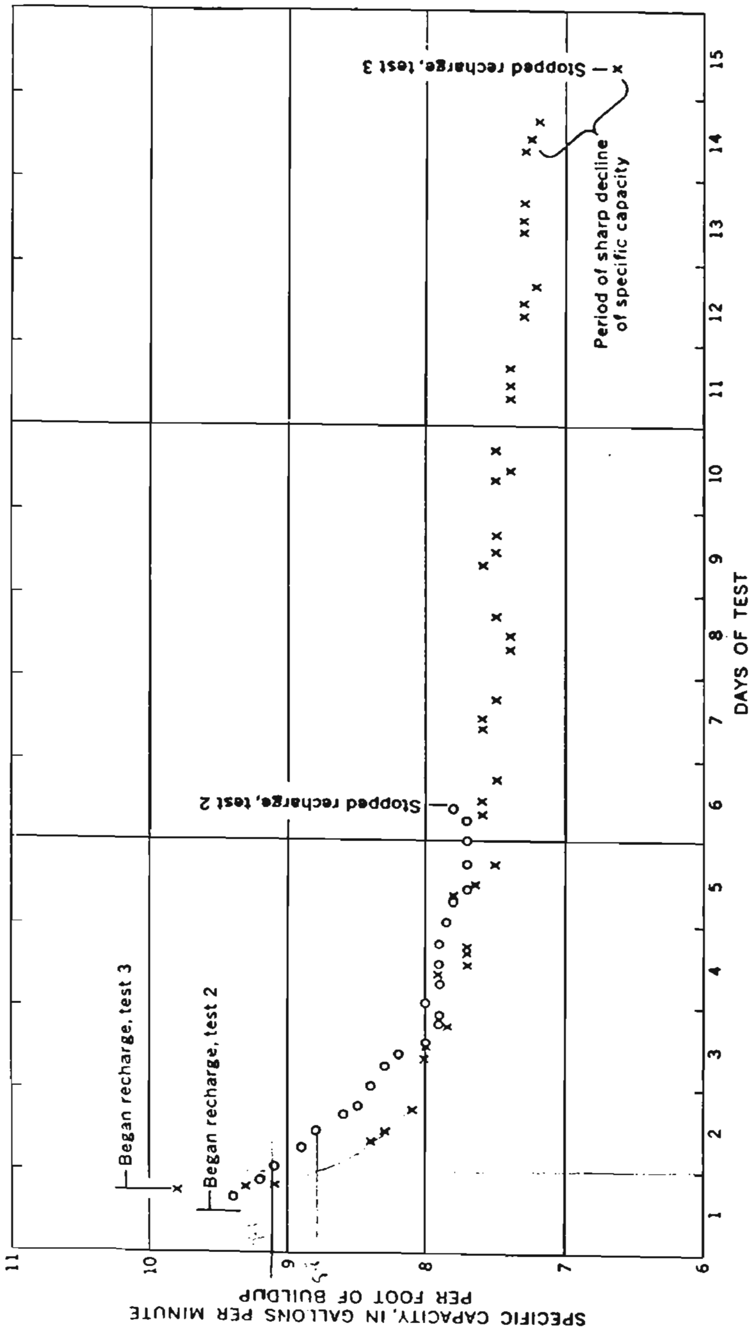

FIGURE 6.—Changes in specific capacity of the injection well during recharge tests 2 and 3.

SIGNIFICANCE OF THE TESTS

Results of the tests indicate that conditions are generally favorable for additional injection of Salem municipal-supply water through recharge well 10K4. However, some possible effects of long-term injection, such as changes in chemical conditions within the aquifer, may not be determined from information available from the tests. The ultimate success of long-term artificial recharge in this area might rest largely upon cumulative effects that may not become apparent until recharge has continued for long periods, or upon economic or other considerations that are beyond the scope of this study.

CHANGES IN THE PHYSICAL AND CHEMICAL CHARACTER OF THE GROUND WATER

The injection tests caused only minor changes in the character of the water in the main confined aquifer near the well, largely because of the close similarities of the recharge water and the native ground water. Temperature and sediment content of water pumped from the recharge well before and after the tests were virtually the same; even the dissolved-oxygen content was similar, owing to the unusually high concentration of oxygen in the ground water near the well before recharging was begun. (See p. F14.)

The small magnitude of overall changes in chemical character of the ground water is readily seen from a comparison of the analyses in table 4, especially the analyses for samples collected during the prerecharge pumping test (February 28, 1962) and pumping test 3 (May 21, 1962). Comparison of those analyses shows that, although the total dissolved solids and the specific conductance of the ground water were reduced somewhat as a result of mixing with the less mineralized recharge water, no large changes occurred in the concentrations of most of the individual constituents tested. Concentrations of silica and sodium, however, were reduced to about one-half and bicarbonate to about two-thirds of their respective prerecharge values. These reductions probably were due to dilution rather than to precipitation or any other chemical reactions. Therefore, the reductions may be considered as temporary changes that diminished and disappeared entirely as the recharge water was gradually assimlated into the native ground water.

Perhaps the most interesting chemical change was the progressive increase in sulfate concentration, which coincided exactly with decreasing bicarbonate concentration that occurred during pumping test 3. No reason could be determined for this apparent shift in anion concentrations, and the test data are too few to indicate how much further the shift would have progressed if the pumping test had continued.

The anomalously high iron concentration (2.0 mg/l) in the first sample collected during pumping test 1 (table 4) probably does not reflect the normal dissolved-iron content of the water. Instead, it probably represents iron that was dissolved from basalt particles in the turbid sample by acid that was added to the sample before the analysis.

EFFECTS ON THE AQUIFER AND THE RECHARGE WELL

BUILDUP OF WATER LEVELS

The injection of water into recharge well 10K4 caused a measurable rise in level in most of the observation wells, especially during the longer periods of recharge (pl. 2). Exceptions were at well 3H1 (Butler well), which taps a zone not connected with the main confined aquifer, and at wells 3M1 (Madrona well) and 9P1 (Steinke well), both of which tap marginal parts of the main aquifer at points distant from the recharge well. At the latter two wells, any rises in response to the recharge tests apparently were masked by barometric fluctuations. The injection of water during recharge test 3 caused a maximum buildup of 126 feet in the level in the recharge well. This caused a rise of as much as 4.5 feet in well 10K2 (Park well 1) and more than 2 feet each in wells 9J1 (Arlene well) and 10E2 (Fir Dell well). The recharge tests apparently also caused some rise, probably only about 1 foot, in well 9K1 (United Growers well); however, the response in the latter well during recharge tests 2 and 3 was largely masked by drawdown because of testing and pumping of the well itself.

The water-level changes resulting from the tests were superimposed on a general seasonal rising trend in levels, largely reflecting natural recharge and recovery from record low pumping levels in the previous year (1961). Therefore, the persistence of water-level rises that resulted from the artificial recharge could not be clearly defined. However, at least in the wells nearest and most responsive to the recharge well, and especially in well 10K2, there was a marked steepening of the rising trend, or a series of steplike rises, that clearly coincided with the period of artificial-recharge tests (pl. 2).

The highest 1962 levels in wells that tap the main confined aquifer occurred in July of that year (pl. 2). It is not known how much lower, if any, the high levels would have been without the artificial recharge.

The combined effects of the regional water-level rise and the buildup of levels from the artificial-recharge tests resulted in a significant decrease in the depth of the preexisting cone of depression in the potentiometric surface of the main aquifer (fig. 4).

SPECIFIC CAPACITY

Changes in specific capacity of the recharge well were used during all the tests to detect clogging and to judge the degree of clogging and the effectiveness of redevelopment of the well. The changes from test to test are summarized in table 1, and the specific-capacity values during recharge tests 2 and 3 are plotted in figure 6.

The rapid decline of specific capacity for the early parts of the recharge tests is a normal result of the buildup of a potentiometric mound in the vicinity of the recharge well (fig. 6). The most significant elements of figure 6 relate to the values plotted for recharge test 3 after the rapid decline in the first 2 days of the test. Even though differences between consecutive values (caused by variations in recharge rate, barometric pressure, and pumping of well 9K1) sometimes exceeded 0.1 gpm per foot, the trend of changes in specific capacity became more gentle and predictable after that early rapid decline. The greatest change, a decline of 0.6 gpm per foot, occurred during a 15½-hour interval from the 14th to the 15th days. This decline together with lesser declines shown by two preceding values, clearly constituted a deviation from the previous trend of the specific-capacity values. This sharp decline of specific capacity is reflected in the hydrograph of the recharge well (pl. 2), which shows a sharp buildup of the level in the well during the last day of recharge test 3.

A sudden decreasing trend in specific capacity of a recharge well (shown by a sudden increasing rate of buildup of water level) may result from progressive clogging of the well or aquifer, or from other causes such as (1) a regional rise of water levels; (2) a reflection of the recharge mound reaching a hydraulic boundary, such as a termination of the aquifer or a decrease in its transmissibility; or (3) a decreased effective aquifer permeability owing to a decrease in temperature, and resultant greater viscosity, of the water being injected. Of these possible causes, a regional rise in water levels was discounted inasmuch as levels in none of the observation wells were rising nearly so rapidly. Also, because the temperature of the recharge water injected during this test was virtually the same as that of native ground water, a significant increase in viscosity was not possible.[2] Therefore, the conclusion reached was that, although the rapid buildup of level and decrease in specific capacity might be partly due to a hydraulic-boundary effect, a termination of the test was warranted by the possibility that serious clogging was occurring.

The specific-capacity data in table 1 include unadjusted values based on the average rate of pumping or recharge during each test period and the maximum drawdown or buildup of levels measured near the end of that period. These specific-capacity values have not been corrected for possible short-term barometric effects nor for differences in duration of some of the pumping tests; however, any inaccuracies that may result from those influences or from the minor changes in water temperature are believed to be too small to affect the general relationships shown by the table.

As the table shows, recharge tests 2 and 3 caused some reduction in specific capacity; that is, the pumping specific capacity following each of these periods of recharge was somewhat less than it was before the corresponding recharge period. The reductions are believed to have been caused by partial clogging of the aquifer in the vicinity of the recharge well. The differences in specific capacities before and after recharge indicate the relative degree of clogging. For example, recharge test 2, which caused an apparent reduction in specific capacity of only about 1.8 gpm per foot (about 13 percent of the prerecharge value), produced relatively little clogging. Recharge test 3, however, caused a decrease of 4.8 gpm per foot (34 percent of the prerecharge value) below the specific-capacity value for pumping test 2A, a decrease which suggests that a significant degree of clogging had occurred.

Clogging probably was caused chiefly by sediment carried in the recharge water, and to a lesser extent by bubbles of air coming out of solution. Other possible clogging agents, such as chemical precipitates, probably were not significant in these tests. Appreciable amounts of sediment, consisting mostly of sand- and silt-size particles, were carried into the well during each of the tests. The sediment content of the recharge water was greatest during recharge test 2 (table 5), when as much as 2,000 pounds of sediment may have been deposited in the well and adjacent aquifer materials. Several hundred pounds of sediment may also have been deposited during the longer recharge test 3, even though only a few of the daily samples of recharge water contained measurable amounts of sediment (table 5). Unfortunately, the recharge well could not be sounded without removing the pump; so the accumulation and removal of sediment in the bottom of the well could not be measured directly.

The dissolved-oxygen analyses (table 4) show that the recharge water contained abundant dissolved air; however, bubbles of air doubtless were much less important as clogging agents in these tests than they had been in the earlier artificial-recharge tests at The Dalles, Oreg. Relatively little of the air that was dissolved in the Salem Heights recharge water came out of solution during the injection process, as shown by the dissolved-oxygen concentrations in table 4. In that table, comparisons of the concentrations for the injected water with those for the water subsequently pumped from the recharge well show a reduction of dissolved oxygen of generally less than 20 percent during these injection tests. In contrast, most of the dissolved oxygen in The Dalles recharge water came out of solution before the water was pumped back to land surface (Foxworthy and Bryant, 1967, p. 50–53).

The sediment and other clogging agents were adequately removed by combined pumping and surging of the recharge well, but not by pumping alone. As shown by table 1, the surging operations after recharge tests 2 and 3 increased the specific capacity of the well to values greater than those of the prerecharge specific capacity. This result apparently occurred because the well had not been systematically cleaned and redeveloped since being placed in service by the water district.

RECOVERY OF THE INJECTED WATER

During the pumping tests and surging operations that followed the three periods of recharge, about 770,000 gallons of water was removed from the recharge well. This figure is partly estimated, because the operation of the flowmeter on the blowoff line was erratic during surging. This volume was only about 3 percent of the total injected; therefore, the net volume of water added to the ground-water reservoir was 97 percent of that injected.

The water pumped from the well following the three periods of recharge consisted of mixtures of recharge water and native ground water in varying proportions. The specific-conductance determinations (table 4) indicate that roughly two-thirds of the water withdrawn during the pumping tests was recharge water.

[2] In the range of temperatures of the water pumped from the recharge well during this study (9°–12°C, or 49°–53°F), a temperature change of 1°C causes a corresponding change in specific capacity of about 3 percent.

METHODS AND TECHNIQUES FOR FURTHER ARTIFICIAL RECHARGE

The results of the completed study emphasize the importance of certain considerations in the design of a system for additional subsurface injection into the main confined aquifer and suggest techniques that would enhance the chances of success in any subsequent artificial-recharge operations of this type.

No serious problems are foreseen in connection with additional artificial recharge through well 10K4. The recharge operations in this study caused no apparent permanent decrease in the water-yielding capacity of the well or aquifer materials and no apparent damage to pumping equipment. However, the use of another well designed especially for injection probably would allow the greatest flexibility of artificial-recharge operations and the establishment of conditions even more favorable for long-term injection with the least risk to the water district's pumping capacity.

In any system for subsurface injection, every effort should be made to prevent the entrainment of air in the recharge water; also, unless the recharge water is degassed before injection, any dissolved air should be largely kept in solution. To this end, the recharge water should be injected into the well in a full pipe under pressure, rather than being allowed to enter by free fall. During the recharge tests previously described, the desired condition was achieved by injecting water through the impellers of the pump; the restriction of flow through the impellers was sufficient to create a large pressure drop there. If future injection is undertaken through a separate pipe or pipes, adequate back pressure can be produced by means of a fixed nozzle (reducer) or a controllable valve at the lower end of the injection pipe. Where possible, sharp pressure reductions should be prevented at other points in the system conveying the recharge water.

A recharge well should be considered as a piece of equipment that will require periodic maintenance and repair, as by cleaning or redevelopment; it eventually may need to be replaced. The information obtained from the relatively short recharge experiments that were conducted during this study is insufficient for a realistic prediction of the useful life of a recharge well that taps the main confined aquifer in the Salem Heights area. Even under the best conditions, however, flushing by pumping or surging might be needed sufficiently often that a permanently installed pump would be desirable in such a recharge well. Also, the large quantities of sediment that entered the well during the injection tests indicate the need for a sediment trap in the piping.

The value of adequate background information for planning and designing artificial recharge through wells and for interpreting and alleviating problems that may arise cannot be overemphasized. An adequate foundation should include an understanding of the ground-water system to be recharged and how the system functions; knowledge of the chemical, physical, and biotic character of the recharge water and the native ground water; and recognition of the possible problems and risks associated with the artificial recharge.

Similarly, various operational data are needed for evaluating results of artificial recharge through wells. Minimum data include records of the volumes and rates of water injection and withdrawal; the types, degree, and times of water treatment; fluctuations of ground-water levels; and periodic determinations of the physical and chemical character of the recharge and ground waters.

Hydraulic-boundary effects can be a significant factor in the rate of water-level buildup during subsurface injection, especially where the aquifer is limited in extent. In the present study, for example, an impermeable boundary reflecting the lateral termination of the main confined aquifer might have contributed to a rapid buildup of levels such as were measured at the recharge well near the end of recharge test 3. Although the data obtained during this study were not adequate for a full evaluation of boundary effects, such evaluation might be possible using the best obtainable data from a longer pumping test (Ferris and others, 1962, p. 144–166). A permeable-boundary effect, which would tend to diminish the rate of buildup of water levels, also is possible where a permeable zone, normally unsaturated, becomes inundated during injection operations. Boundary effects should be suspected when anomolous patterns of water-level buildup occur after about the same elapsed time during different periods of injection in a well.

For most subsurface-injection operations wherein the rate of injection cannot be closely regulated, a record of the specific capacity of the recharge well probably is the simplest and most useful single tool for detecting and evaluating clogging and for determining the effectiveness of redevelopment of the well. However, if water levels in the injection well fluctuate widely in response to extraneous influences, such as barometric-pressure changes or pumping from nearby wells, the specific-capacity data may not provide adequate warning of incipient clogging. In such cases, a separate observation well adjacent to the injection well and tapping the injection zone may be needed to provide reference water levels. Levels in the two wells would respond almost identically to boundary affects and extraneous causes and, for a specific injection rate, the hydraulic gradient between the two wells would be virtually constant. However, any clogging of the injection well or of the aquifer material between it and the nearby observation well would result in a steepening of the hydraulic gradient and an increase in the difference between water levels in the two walls.

CONCLUSIONS

The major conclusions resulting from this study are:

1. A total of 24.5 million gallons of water from the Salem municpal water system was injected into the Salem Heights Water District's Park well 2 during a total recharge time of 20.5 days, at an average rate of 830 gpm (1.2 million gpd). If water could be injected into the well at that rate for a total of 200 days during October to May, when excess water is normally available in the Salem system, the total recharge would amount to 240 million gallons, or about 740 acre-feet per year. This would be equivalent to the volume stored by a 160-acre surface reservoir (half a mile on a side) 4.6 feet in depth.
2. The character of the main confined aquifer and the availability and quality of the Salem city water are unusually favorable for artificial recharge of the aquifer by injection through wells. Because the aquifer materials are highly permeable, they allow a rapid spread of pressure effects from the recharge well and are less subject to clogging than materials having smaller pore spaces. The city water mixed with the native ground water without apparent undesirable chemical effects or deterioration of the bacteriological purity of the ground water.
3. The buildup of head in the main confined aquifer during periods of artificial recharge dissipated rapidly, and any residual buildup was masked by a seasonal rising trend in ground-water levels within a few days after the recharge had stopped. The rapid dissipation of the recharge mound indicates that the benefit from subsurface injection would be spread through the area of the main aquifer rather than being restricted to the vicinity of the recharge well. Moreover, the benefit would persist because the geologic and hydrologic conditions in the Salem Heights area preclude the escape of the injected water from the area by subsurface migration. The recharge tests contributed to the reduction of a preexisting cone of depression in the potentiometric surface of the main aquifer. None of the tests, however, was long enough to indicate the amount of buildup of regional levels that might be achieved during long-term injection.
4. The artificial-recharge tests caused some decrease in the specific capacity of the recharge well. The principal cause of the decrease was a partial clogging of the aquifer materials in the vicinity of the well by (a) sediment carried in the recharge water and (b) probably by bubbles of air that came out of solution from the recharge water. Virtually all the injected sediment was removed by surging (intermittent pumping) with the existing pump, and the specific capacity was thereby restored to values greater than prerecharge specific capacity.
5. No serious problem can be foreseen in connection with additional subsurface injection using the Salem city water, either through the pump and piping into Park well 2 or through a different well and injection system of adequate design. To minimize plugging, the quantity of sediment entering the injection well should be greatly reduced. The data and experience gained during this study, however, do not completely eliminate the possibility that some unforeseen problem may arise during longer periods of recharge.
6. Adequate background information and operational data are essential for effective planning, operation, and evaluation of artificial recharge through wells. The necessary foundation includes (a) an understanding of the ground-water system to be recharged and know it functions; (b) a knowledge of the chemical, physical, and biotic character of the recharge water and the native ground water; and (c) a recognition of possible problems and risks associated with the artificial recharge. The minimum operational data include records of the volumes and rates of water injected and withdrawn; the type, degree, and time of water treatment; fluctuations of ground-water levels; and periodic determination of the character of the recharge and ground waters. Changes in specific capacity of the injection well provide a generally effective warning of incipient clogging and an adequate basis for evaluating redevelopment of the well.

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William C. Knight   10 May 1977

The following are the results of the chemical analysis performed on the City water supply, and Park Well #2 - samples collected on 24 February 1977.

	City Water	Park Well #2
Suspended Solids	9	9
Volatile Suspended Solids	5	3
Total Solids	30	82
Volatile T. Solids	0.0	10
Silica (SiO_2)	8.5	45.0
Aluminum (Al)	0.07	0.04
Iron (Fe)	<0.1	<0.1
Calcium (Ca)	1.42	2.40
Magnesium (Mg)	0.57	0.27
Sodium (Na)	2.7	5.35
Sulfate (SO_4)	8.0	8.5
Chloride (Cl)	0.6	1.1
Fluoride (F)	0.14	0.26
Nitrate (NO_3)	<0.05	0.15
Copper (Cu)	0.01	0.02
Hardness as $CaCO_3$)	6.3	7.3
Total Alkalinity	25	35
Conductivity (micromhs)	50	65

Ground water
Recharge [illegible]

Above tests performed by City Laboratory personnel.

R.J. Porpart
Sanitary Analyst
Ph. 393-[illegible]806

EXHIBIT A
Page 1 of 1

MEMORANDUM

TO: Herb Arnold/Sanitary Engineer

FROM: Ray Parpart/Sanitary Analyst *R Parpart*

DATE: 5 October 1977

SUBJECT: GROUND WATER RECHARGE

Below are the chemical analysis of the City Wells being recharged with the date of sample collection. All results are parts per million except as indicated.

	Park Well #2			Friendship		Arlene	
	7-22-77	7-27-77	8-29-77	7-22-77	8-5-77	7-27-77	MCL (2)
Aluminum	(1) 0.1	(1) 0.1	(1) 0.1	(1) 0.1	(1) 0.1	(1) 0.1	
Arsenic	(1) 0.005	(1) 0.005	(1) 0.005	(1) 0.005	(1) 0.005	(1) 0.005	(2) 0.05
Barium	(1) 0.05	(1) 0.05	(1) 0.05	(1) 0.05	(1) 0.05	(1) 0.05	(2) 1.0
Cadmium	(1) 0.005	(1) 0.005	(1) 0.005	(1) 0.005	(1) 0.005	(1) 0.005	(2) 0.010
Calcium	6.7	6.9	6.0	12.0	9.8	6.7	
Chloride	2.75	1.50	1.00	3.00	3.00	3.00	
Chromium	0.075	0.025	0.038	0.030	0.030	0.040	(2) 0.05
Copper	(1) 0.02	(1) 0.02	(1) 0.02	(1) 0.02	(1) 0.02	(1) 0.02	
Fluoride	0.49	0.69	0.62	0.118	0.151	0.7	
Iron	(1) 0.2	(1) 0.2	(1) 0.2	(1) 0.2	(1) 0.2	(1) 0.2	
Lead	0.050	0.400	-	0.060	0.090	0.009	(2) 0.05
Magnesium	0.28	0.46	0.12	0.23	0.13	0.15	
Manganese	0.0098	0.042	0.060	0.009	0.070	0.045	
Mercury	(1) 0.0005	(1) 0.0005	(1) 0.0005	(1) 0.0005	(1) 0.0005	(1) 0.0005	(2) 0.002
Nickel	(1) 0.02	(1) 0.02	(1) 0.02	(1) 0.02	(1) 0.02	(1) 0.02	
Phosphate	0.06	0.03	0.05	0.15	0.15	0.05	
Potassium	0.56	0.49	0.61	0.98	0.41	0.50	
Selenium	0.0022	0.0030	0.0060	0.0042	0.0038	0.0030	(2) 0.01
Silica	24.0	22.0	26.0	40.0	38.0	25.0	
Silicon	0.090	0.095	0.091	0.095	0.180	0.200	
Silver	(1) 0.05	(1) 0.05	(1) 0.05	(1) 0.05	(1) 0.05	(1) 0.05	(2) 0.05
Sodium	0.92	1.80	2.00	5.00	7.80	1.90	
Sulfate	13.5	14.0	15.0	11.0	10.5	11.0	
Zinc	0.009	0.008	(1) 0.005	(1) 0.005	(1) 0.005	0.05	
Ammonia	0.16	(1) 0.02	-	(1) 0.02	-	(1) 0.02	

EXHIBIT B
Page 1 of 2

	Park Well #2			Friendship		Arlene	
	7-22-77	7-27-77	8-29-77	7-22-77	8-5-77	7-27-77	MCL (2)
Nitrate	1.70	(1) 0.05	-	0.40	-	0.05	(2) 10.0
Conductivity	(3)77.0	(3)69.0	(3)70.0	114.0	110.0	70.0	
pH	5.69	6.90	6.00	6.00	6.00	6.70	
Hardness (Ca,Mg)	17.88	19.12	15.48	30.91	25.0	17.35	
Alkalinity	20.0	15.0	-	48.0	-	18.0	
Turbidity	(4) 4.8	0.5	0.5	3.2	0.4	0.9	(2) 1.0

(1) indicates Less Than

(2) MCL indicates Maximum Contaminant Levels - EPA Primary Drinking Water Regulations

(3) indicates umho

(4) indicates Nephelometric Turbidity Units

cc: William C Light
Howard Rice

ir

EXHIBIT B
Page 2 of 2

TABLE 1.—*Summary of recharge and pumping tests, well 8/3W-10K4*

Test designation	Began		Ended		Approximate duration	Quantity of water injected (i) or pumped (p) (thousands of gallons)	Average rate (gpm)	Maximum buildup (+) or drawdown (−) of water level (ft)	Specific capacity, measured (gpm per ft)	Water temperature	
	Date 1962	Time	Date 1962	Time						°C	°F
Prerecharge pumping test	Feb. 28	3:30 p.m.	Feb. 28	8:30 p.m.	5 hr	201 (p)	660	46.8(−)	14.3	11-11.6	52-53
Recharge test 1	Mar. 20	8:20 a.m.	Mar. 21	8:30 a.m.	24 hr	1,051 (i)	725	70.6(+)	10.3	8.6-8.8	47.5-48
Pumping test 1	Mar. 21	11:50 a.m.	Mar. 21	4:50 p.m.	5 hr	175 (p)	583	30.7(−)	14.7	9.3-10	48.8-50
Recharge test 2	Apr. 16	11:40 a.m.	Apr. 21	9:40 a.m.	5 days	5,816 (i)	821	100.9(+)	7.7	9.3-10	48.8-50
Pumping test 2	Apr. 24	9:10 a.m.	Apr. 24	2:10 p.m.	5 hr	185 (p)	617	47.9(−)	12.9	10-10.5	50-51
Pumping test 2A (after surging) [1]	May 1	2:25 p.m.	May 1	4:32 p.m.	2 hr	90 (p)	704	30.6(−)	17.8		
Recharge test 3	May 1	5:00 p.m.	May 15	9:02 a.m.	15 days	17,608 (i)	834	120.0(+)	6.6	10.6-11.6	51.2-53
Pumping test 3	May 21	9:12 a.m.	May 21	2:14 p.m.	5 hr	205 (p)	679	52.3(−)	13.0	11.6	53
Pumping test 3A (after surging) [2]	May 21	4:13 p.m.	May 21	6:13 p.m.	2 hr	89 (p)	730	43.2(−)	17.1		

Total amount injected .... million gallons .. 24.5
Total injection time .... days .. 20.5
Average injection rate .... million gallons per day .. 1.2
Total pumped from well during tests .... gallons .. 970,000

[1] About 9,000 gallons removed during 40± minutes of surging.
[2] About 20,000 gallons removed during 90± minutes of surging.

TABLE 2.—*Records of selected drilled wells in the Salem Heights area*

Well No.: See text for description of well-numbering system.
Finish: Casing continuous, unperforated, and open at lower end, except as noted. Perforated in depth interval shown, in feet below land-surface datum.
Altitude: Altitude of land-surface datum at well, in feet above mean sea level, determined by spirit leveling.
Water level: Depth to water below land-surface datum, measured by air line and pressure gage, electric sounder, or steel tape.

Type of pump: T, turbine; N, none.
Use: Ind, industrial, N, unused; Obs, observation of water-level fluctuations; PS, public supply.
Remarks: Temp, temperature of water in degrees Celsius (followed by temperature in degrees Fahrenheit within parentheses). Remarks on adequacy of supply were reported by owner or driller.

Well	Owner's designation	Year completed	Depth of well (ft)	Diameter of well (in.)	Depth of casing (ft)	Finish	Water-bearing zone(s): Depth to top (ft)	Water-bearing zone(s): Thickness (ft)	Water-bearing zone(s)—Continued: Character of material	Altitude (ft)	Water level: Feet below datum	Water level: Date	Type of pump and horsepower	Well performance: Yield (gpm)	Well performance: Drawdown (ft)	Use	Remarks
8/3W-3H1	Butler well 4	1954	296	8	81	Lower part uncased.	>178		Basalt	316.2	29 148.8	6- -54 4-19-62	T, 25	225		PS	
3M1	Madrona well 8	1958	350	12	97	do	248	60	do	352.7	177 199.0	2-20-58 2-28-62	N	50	97	Obs	Temp 11 (52). Drilled for public supply. Yield inadequate.
9J1	Arlene well 7	1957	475	12	82	do	382	93	Basalt, shattered, vesicular.	429.3	243 281.1	3-30-57 2-27-62	T, 100	600	101	PS	Temp 13 (56).
9K1	Cannery well (United Growers, Inc.).	1947	630	10	431	Perforated 290-426 ft, lower part uncased.	398	33	Basalt, broken	465	275 313.4	2- -47 2-28-62	T, 100	400	59	Ind	
9P1	Steinke well 11	1959	460	12	100	Lower part uncased.	346		Basalt, vesicular	471.1	316 321	10-20-59 3-13-62	N	330	48	Obs	Future public-supply use.
10E2	Fir Dell well 9	1950	617	12-10	448	Perforated 350-380 ft, lower part uncased.			Basalt	420.9	256 260.9	11-15-59 2-27-62	T, 40	230	59	PS	
10K2	Park well 1	1954	292	8	104	Lower part uncased.	285 187	7 2	Basalt, vesicular	385.6	102 221.7	8- -54 2-26-62	T, 50	1,000	5(?)	PS	
10K4	Park well 2	1959	345	12	107	do	256	39	Basalt, broken, vesicular.	386	212 230.3	4- 9-59 2-23-62	T, 100	920	78	PS	Temp 12 (53). Injection well during recharge tests.
11N1	Hall well 12	1960	270	12	105	do	226	26	Basalt, vesicular	425	19.2 21.9	2- 4-60 4-19-62	N	91	136	N	Drilled for public supply; yield inadequate.

TABLE 3.—*Drillers' logs of wells*

[Drillers' designations are edited for consistency of presentation, but otherwise unchanged. Stratigraphic and parenthetical designations are by the writer. Depths are in feet below land surface at well]

8/3W-3H1

[Salem Heights Water Dist. (Butler well 4). Altitude 316.2 ft. Drilled by Duffield Bros., 1954]

Materials	*Thickness (ft)*	*Depth (ft)*
Soil and weathered Columbia River Group:		
Shale and boulders (weathered basalt)	29	29
Columbia River Group:		
Basalt, fractured	9	38
Basalt	73	111
Andesite	13	124
Basalt	7	131
Basalt, vesicular	12	143
Basalt; 7–8 gpm yield at 178-ft depth	35	178
Basalt	51	229
Andesite	14	243
Basalt, vesicular	50	293
Basalt	3	296

8/3W-3M1

[Salem Heights Water Dist. (Madrona well 8). Altitude 352.7 ft. Drilled by Duffield Bros. 1958]

Materials	*Thickness (ft)*	*Depth (ft)*
Soil and weathered Columbia River Group:		
Soil, red	2	2
Bouldery formation	10	12
Columbia River Group:		
Basalt, gray and black	71	83
Basalt, with shale lenses	8	91
Basalt, hard, brown	15	106
Basalt, decomposed	6	112
Basalt, black and gray	117	229
Basalt, fractured	16	245
Basalt, gray, fractured from 248 to 264 ft	47	292
Basalt, black, vesicular	16	308
Marine sedimentary rocks:		
Clay, yellow to red	32	340
Shale and marine deposits, gray, hard	10	350

TABLE 3.—*Drillers' logs of wells*—Continued

8/3W-9J1

[Salem Heights Water Dist. (Arlene well 7). Altitude 429.3 ft. Drilled by Duffield Bros., 1957]

Materials	*Thickness (ft)*	*Depth (ft)*
Soil and weathered Columbia River Group:		
Clay and decomposed rock	46	46
Columbia River Group:		
Basalt, black	70	116
Basalt, black, shattered, water-bearing; static water level of 46 ft at 128-ft depth	12	128
Basalt, black, very hard	153	281
Basalt, shattered, carbonated	7	288
Basalt, gray, very hard	21	309
Basalt, vesicular; static water level 136 ft; 35-gpm yield	4	313
Basalt, gray, very hard	58	371
Basalt, broken and vesicular, highly carbonated; static water level 242 ft	11	382
Basalt, shattered, vesicular, caving, water-bearing	93	475

8/3W-9K1

[United Growers, Inc. Altitude about 465 ft. Drilled by Studebaker Bros., 1947]

Materials	*Thickness (ft)*	*Depth (ft)*
Soil and weathered Columbia River Group:		
Soil and clay	68	68
Columbia River Group:		
Basalt, broken	15	83
Basalt, broken, with occasional seams, water-bearing at 84-ft depth, open crevice at 273-ft depth; bailed 70 gpm	190	273
Basalt; static water level declined from 40 to 273 ft in depth range of 273–279 ft	92	365
Basalt, broken, with many seams; main water-bearing zone in depth range of 398–431 ft	68	433
Basalt, with occasional seams	71	504
Marine sedimentary rocks:		
"Rock" and shale, alternate layers	126	630

TABLE 3.—*Drillers' logs of wells*—Continued

Materials	Thickness (ft)	Depth (ft)
8/3W-9P1		
[Salem Heights Water Dist. (Steinkle well 11). Altitude 471.1 ft. Drilled by Duffield Bros., 1959]		
Soil and weathered Columbia River Group:		
Clay	4	4
Clay, red	24	28
Clay, yellow	18	46
Columbia River Group:		
Basalt, black, hard	216	262
Basalt, vesicular, very open; pieces of very light shale, tree limbs, and twigs	60	322
Basalt, black, hard	24	346
Basalt, vesicular, water-bearing	6	352
Basalt, shattered, "eroded," black with gray streaks	60	412
Basalt, black, hard	16	428
Basalt, black, soft	5	433
Marine sedimentary rocks:		
Shale, soft, squeezes	17	450
8/3W-10E2		
[Salem Heights Water Dist. (Fir Dell well 9). Altitude 420.9 ft. Drilled by Duffield Bros., 1950]		
Soil and weathered Columbia River Group:		
Clay, surface	4	4
Clay, yellow to red	41	45
Columbia River Group:		
Basalt, black, hard	55	100
Basalt, black	17	117
Basalt, gray, hard	7	124
Basalt, black	11	135
Basalt, gray, hard	26	161
Basalt, gray, fractured, decomposed	6	167
Basalt, black	21	188
Basalt, gray, hard	78	266
Basalt, gray	25	291
Basalt, brown to black	28	319
Basalt, black, hard	21	340
Basalt, vesicular, carbonated	12	352
Basalt, black	16	368
Marine sedimentary rocks:		
Clay, yellow and white	19	387
Shale, gray, soft	11	398
Shale, gray, hard, "crystalline"	44	442
Shale, gray, hard; gray, white, and yellow granules of calcite, opal, quartz, and garnet	23	465
Shale, sandy	33	498
Sandstone, quartz and opal; calcite "binder"	97	595
Shale, gray, soft, sticky	22	617

TABLE 3.—*Drillers' logs of wells*—Continued

Materials	Thickness (ft)	Depth (ft)
8/3W-10K2		
[Salem Heights Water Dist. (Park well 1). Altitude 385.6 ft. Drilled by Duffield Bros., 1954]		
Soil and weathered Columbia River Group:		
Clay, red	65	65
Ash, volcanic, compacted	32	97
Columbia River Group:		
Basalt	23	120
Basalt, fractured	8	128
Basalt, layered, solid, fractured and broken	51	179
Basalt	8	187
Cinders (basaltic); water level 45 ft	2	189
Basalt	71	260
Andesite	25	285
Basalt, vesicular; water level dropped to 192 ft	7	292
8/3W-10K4		
[Salem Heights Water Dist. (Park well 2). Altitude 386.0 ft. Drilled by Duffield Bros., 1959]		
Soil and weathered Columbia River Group:		
Clay, surface	3	3
Clay, red and yellow	57	60
Columbia River Group:		
Basalt, black, hard	101	161
Basalt, gray, hard	56	217
Basalt, vesicular; static water level 123 ft	5	222
Basalt, black	34	256
Cinders, basaltic; pieces of calcified basalt, smooth, rounded	27	283
Basalt "rocks," ¼-in. to 1½-in	12	295
Basalt, black	33	328
Basalt, black, soft like coal	3	331
Marine sedimentary rocks:		
Clay, yellow	9	340
Shale, gray, soft	5	345
8/3W-11N1		
[Salem Heights Water Dist. (Hall well 12). Altitude about 425 ft. Drilled by Duffield Bros., 1960]		
Soil and weathered Columbia River Group:		
Clay, soil	3	3
Clay, yellow	15	18
Boulders and red clay	28	46
Columbia River Group:		
Basalt, black, hard; yielded 75 gpm at 60-ft depth	59	105
Basalt, black, hard	67	172
Basalt, brown, vesicular, medium-grained, weathered	8	180
Basalt, black, hard, fine-grained	12	192
Basalt, light-brown, weathered	16	208
Basalt, black, coarse-grained	18	226
Basalt, vesicular, weathered	26	252
Marine sedimentary rocks:		
Shale, reddish-brown	8	260
Shale, blue-gray, squeezes	10	270

TABLE 4.—*Chemical analyses of waters from the Salem Heights area*

[Milligrams per liter except as noted. Samples collected at sampling tap in pipeline at recharge well 8/3W-10K4 except as noted. Analyses by the U.S. Geological Survey except as noted. All city of Salem water, including recharge water, was chlorinated; all recharge water was fluoridated. (See text.) *Remarks.*—Tests during which samples were collected are designated by "P" (pumping test) or "R" (recharge test) followed by test number, or by "PR" (prerecharge pumping test). See summary of tests, table 1]

Source	Date and time of collection	Temperature (°C)	Silica (SiO_2)	Aluminum (Al)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)
City of Salem water supply.	2-14-61	...	15	0.5	0.04	4.2	1.7	6.0	6.2	16.4	1.1
Do	10-30-61 4:45 p.m.	11.7	16	...	.01	5.0	.7	2.5	.6	22	1.6
Recharge well (8/3W-10K4).	10-30-61 4:20 p.m.	12.7	52	...	.04	4.5	1.7	7.3	2.0	37	3.6
Do	2-28-62 4:45 p.m.	11	48	...	.00	5.0	1.4	6.5	1.9	34	2.8
Do	2-28-62 5:35 p.m.	11.4	48	...	...	...	...	...	...	35	...
Do	2-28-62 8:00 p.m.	11.6	48	...	...	...	...	...	...	37	...
City of Salem water supply.	3- 2-62 4:20 p.m.	6.7	14	...	.07	4.0	.6	4.2	.5	19	.4
Recharge water	3-20-62 9:15 a.m.	8.8	14	...	.10	...	...	...	...	22	.4
Do	3-21-62 7:10 a.m.	8.8	14	...	.09	...	...	...	...	22	.0
Recharge well (8/3W-10K4).	3-21-62 12:01 p.m.	9.5	29	...	2.0	...	...	...	...	26	3.2
Do	3-21-62 12:20 p.m.	9.5	22	...	.08	4.0	1.2	3.5	.8	23	1.0
Do	3-21-62 3:05 p.m.	10	30	...	.05	...	...	...	...	24	1.4
Do	3-21-62 4:45 p.m.	10	32	...	.06	4.0	1.3	4.3	1.1	26	1.4
Recharge water	4-16-62 7:00 p.m.	9.5	13	...	.15	5.5	.6	3.9	.6	24	.0
Do	4-17-62 6:50 p.m.	9.5	13	...	...	...	...	...	...	24	.4
Do	4-19-62 6:30 a.m.	9.5	14	...	...	...	...	...	...	24	.2
Do	4-21-62 8:52 a.m.	...	14	...	...	...	...	...	...	24	.2
Recharge well (8/3W-10K4).	4-24-62 9:12 a.m.	10.5	21	...	...	...	...	...	...	28	.2
Do	4-24-62 10:20 a.m.	10	24	...	.14	5.5	1.1	4.1	.9	27	1.6
Recharge well (8/3W-10K4).	4-24-62 11:15 a.m.	10	...	...	...	...	...	...	...	...	...
Do	4-24-62 12:15 p.m.	10.2	...	...	...	...	...	...	...	...	...
Do	4-24-62 12:50 p.m.	10	...	...	...	...	...	...	...	...	...
Do	4-24-62 2:07 p.m.	10	20	...	...	...	...	...	...	27	3.4
Recharge water	5- 1-62 6:00 p.m.	10.5	18	...	...	...	...	...	...	26	.8
Do	5- 8-62 5:05 p.m.	10.5	13	...	...	...	...	...	...	21	.6

Date and time of collection	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids: Calculated	Dissolved solids: Residue on evaporation at 180°C	Hardness as $CaCO_3$	Total alkalinity	Specific conductance (micromhos at 25°C)	pH	Color	Dissolved oxygen: Milligrams per liter	Dissolved oxygen: Percent saturation	Remarks
2-14-61	0.7	0.0	0.1	...	32	17.5	...	...	6.9	...	...	...	Data from City of Salem.
10-30-61 4:45 p.m.	2.0	.2	.2	40	41	15	...	45	7.0	0	...	...	Sampled at booster-pump station.
10-30-61 4:20 p.m.	2.5	.2	.5	92	92	18	...	75	7.5	5	...	...	Sampled after pumping 10 min.
2-28-62 4:45 p.m.	2.2	.3	.4	86	83	18	...	72	7.4	0	9.3	84	PR, after pumping 1¼ hr.
2-28-62 5:35 p.m.	2.5	...	...	...	...	18	...	74	7.4	...	8.3	76	PR, after pumping 2 hr 5 min.
2-28-62 8:00 p.m.	2.5	...	...	...	...	10	...	80	7.3	...	6.8	62	PR, after pumping 4½ hr.
3- 2-62 4:20 p.m.	1.8	1.8	.0	37	43	12	...	47	6.9	5	11.7	95	Sampled at booster-pump station after fluoride was added.
3-20-62 9:15 a.m.	...	...	...	...	...	...	18	51	7.3	...	10.8	93	R1, after injecting 55 min.
3-21-62 7:10 a.m.	...	...	...	...	...	...	18	47	7.1	...	10.9	93	R1, after injecting 23 hr.
3-21-62 12:01 p.m.	...	...	...	...	...	...	21	59	7.1	...	...	...	P1, after pumping 2 min; water turbid.
3-21-62 12:20 p.m.	1.8	.5	.1	46	42	15	19	49	7.2	5	11.1	97	P1, after pumping 21 min.
3-21-62 3:05 p.m.	...	...	...	...	...	...	20	52	7.3	...	10.0	87	P1, after pumping 3 hr 6 min.
3-21-62 4:45 p.m.	2.0	.4	.1	60	58	16	21	54	7.2	5	8.6	76	P1, after pumping 4¾ hr.
4-16-62 7:00 p.m.	1.0	1.3	.3	38	38	16	20	52	6.9	5	13.2	115	R2, after injecting 7¼ hr.
4-17-62 6:50 p.m.	1.2	1.3	...	...	...	...	20	51	6.9	...	9.0	78	R2, after injecting 31 hr.
4-19-62 6:30 a.m.	1.2	1.4	...	...	...	...	20	52	6.9	...	10.5	92	R2, after injecting 67 hr.
4-21-62 8:52 a.m.	1.2	1.3	...	...	...	...	20	51	6.9	...	...	...	R2, after injecting 117 hr.
4-24-62 9:12 a.m.	1.2	.0	...	...	...	...	23	56	7.0	...	...	...	P2, after pumping 2 min; water turbid.
4-24-62 10:20 a.m.	1.5	1.0	.3	53	54	18	22	59	7.0	5	9.0	80	P2, after pumping 1 hr 10 min; water contains some sediment.
4-24-62 11:15 a.m.	...	...	...	...	...	...	...	60	...	...	8.9	79	P2, after pumping 2 hr 5 min; water contains some sediment.
4-24-62 12:15 p.m.	...	...	...	...	...	...	...	...	...	...	9.0	80	P2, after pumping 3 hr 5 min; water clear with minor sediment.
4-24-62 12:50 p.m.	...	...	...	...	...	...	...	61	...	...	8.7	77	P2, after pumping 3 hr 40 min; water clear with sand-size sediment.
4-24-62 2:07 p.m.	1.2	1.0	...	...	...	...	...	61	7.2	...	8.5	75	P2, after pumping 4 hr 57 min; water clear with minor sediment.
5- 1-62 6:00 p.m.	1.2	1.1	...	...	...	...	21	55	7.3	...	...	...	R3, after injecting 1 hr; water contains sand-size sediment.
5- 8-62 5:05 p.m.	1.5	1.2	...	...	...	...	17	47	7.0	...	...	...	R3, after injecting 7 days.

TABLE 4.—*Chemical analyses of waters from the Salem Heights area*—Continued

Source	Date and time of collection	Temperature (°C)	Silica (SiO_2)	Aluminum Al	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids: Calculated	Dissolved solids: Residue on evaporation at 180°C	Hardness as $CaCO_3$	Total alkalinity	Specific conductance (micromhos at 25°C)	pH	Color	Dissolved oxygen: Milligrams per liter	Dissolved oxygen: Percent saturation	Remarks
Recharge well (8/3W-10K4).	5-21-62 9:14 a.m.	......	41	......	......	......	......	......	......	32	1.6	2.0	.4	......	......	......	......	26	66	7.0	......	......	......	P3, after pumping 2 min; water turbid.
Do	5-21-62 9:23 a.m.	11.6	28	......	......	......	......	......	......	28	3.2	2.0	.6	......	......	......	......	23	62	7.0	......	8.2	75	P3, after pumping 11 min; water contains sand-size sediment.
Do	5-21-62 10:18 a.m.	11.6	24	......	......	......	......	......	......	26	3.6	2.0	.7	......	......	......	......	21	60	7.0	......	9.1	83	P3, after pumping 1 hr 6 min; water contains sand-size sediment.
Do	5-21-62 12:15 p.m.	11.6	24	......	......	......	......	......	......	25	5.6	2.0	.8	......	......	......	......	20	62	7.0	......	8.6	79	P3, after pumping 3 hr 3 min.
Do	5-21-62. 2:12 p.m.	11.6	24	......	.06	6.5	1.0	3.4	.9	24	6.8	1.5	.8	.2	57	58	20	20	63	7.0	5	7.8	71	P3, after pumping 5 hr; water contains some sediment.

TABLE 5.—*Suspended sediment in waters sampled during artificial-recharge study at Salem Heights*

[Collection points: Unless otherwise noted, samples were collected at sampling tap on injection line at pump]

Source	Date	Time	Concentration (mg/l)
Pretest conditions			
Injection line, from booster-pump station.	3-2-62	4:10 p.m.	0
		4:10 p.m.	3
Recharge test 1			
Injection line, from booster-pump station.	3-20-62	9:13 a.m.	[1] 18
		9:14 a.m.	[1] 40
		10:13 a.m.	5
		10:13 a.m.	[1] 25
		11:20 a.m.	[1] 19
		1:25 p.m.	5
		4:22 p.m.	[1] 34
	3-21-62	12:30 a.m.	5
		7:07 a.m.	[1] 27
Pumping test 1			
Blowoff line, from well 10K4	3-21-62	12:00:30 p.m.	[1] 1,290
Well 10K4	3-21-62	12:01 p.m.	[1] 371
		12:03 p.m.	[1] 162
		12:07 p.m.	[1] 53
		1:30 p.m.	2
		4:00 p.m.	2
		4:40 p.m.	[1] 8
Recharge test 2			
Injection line, from booster-pump station.	4-16-62	11:50 a.m.	[1, 2] 122
		1:40 p.m.	[1] 47
		3:40 p.m.	[1] 20
		6:40 p.m.	[1] 216
	4-17-62	11:45 a.m.	0
		6:50 p.m.	[1] 45
	4-18-62	6:40 p.m.	2
	4-19-62	6:30 a.m.	[1] 12
		6:10 p.m.	0
	4-20-62	11:59 p.m.	3
	4-21-62	8:52 a.m.	7
Pumping test 2			
Well 10K4	4-24-62	9:11 a.m.	[2] 18
		9:12 a.m.	[1] 120
		9:13 a.m.	[1] 678
		9:16 a.m.	[1] 155
		9:21 a.m.	[1] 292
		9:28 a.m.	[1] 48
		10:20 a.m.	[1] 7
		11:16 a.m.	[1] 5
		12:22 p.m.	[1] 50
		1:15 p.m.	[1] 16
		2:08 p.m.	[1] 12

See footnotes at end of table.

See footnotes at end of table.

TABLE 5.—*Suspended sediment at waters sampled during artificial-recharge study at Salem Heights*—Continued

Source	Date	Time	Concentration (mg/1)
Recharge test 3			
Injection line, from booster-pump station.	5- 1-62	5:50 p.m.	[1]119
	5- 2-62	8:13 a.m.	2
	5- 3-62	8:10 a.m.	4
	5- 4-62	8:15 a.m.	0
	5- 5-62	-------------	0
	5- 6-62	-------------	0
	5- 7-62	-------------	0
	5- 8-62	-------------	0
	5- 9-62	-------------	0
	5-10-62	-------------	0
	5-11-62	-------------	0
	5-12-62	-------------	0
	5-13-62	-------------	0
	5-14-62	-------------	0
	5-15-62	-------------	2
Pumping test 3			
Well 10K4-------------------------	5-21-62	8:32 a.m.	[1] 456
		9:13 a.m.	21
		9:14 a.m.	[1] 356
		9:17 a.m.	[1] 155
		9:22 a.m.	[1] 205
		10:14 a.m.	13
		11:34 a.m.	5
		12:20 p.m.	0
		1:12 p.m.	8
		2:12 p.m.	0

[1] Sample contains sand.
[2] Sample rust colored.

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APPENDIX B

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October 26, 1977

Mr. B. T. Van Wormer, Director
Utilities/Public Works Department
City of Salem
City Hall
555 Liberty Street, S.E.
Salem, Oregon 97301

Subject: Groundwater Recharge - J.O. 6070.0020

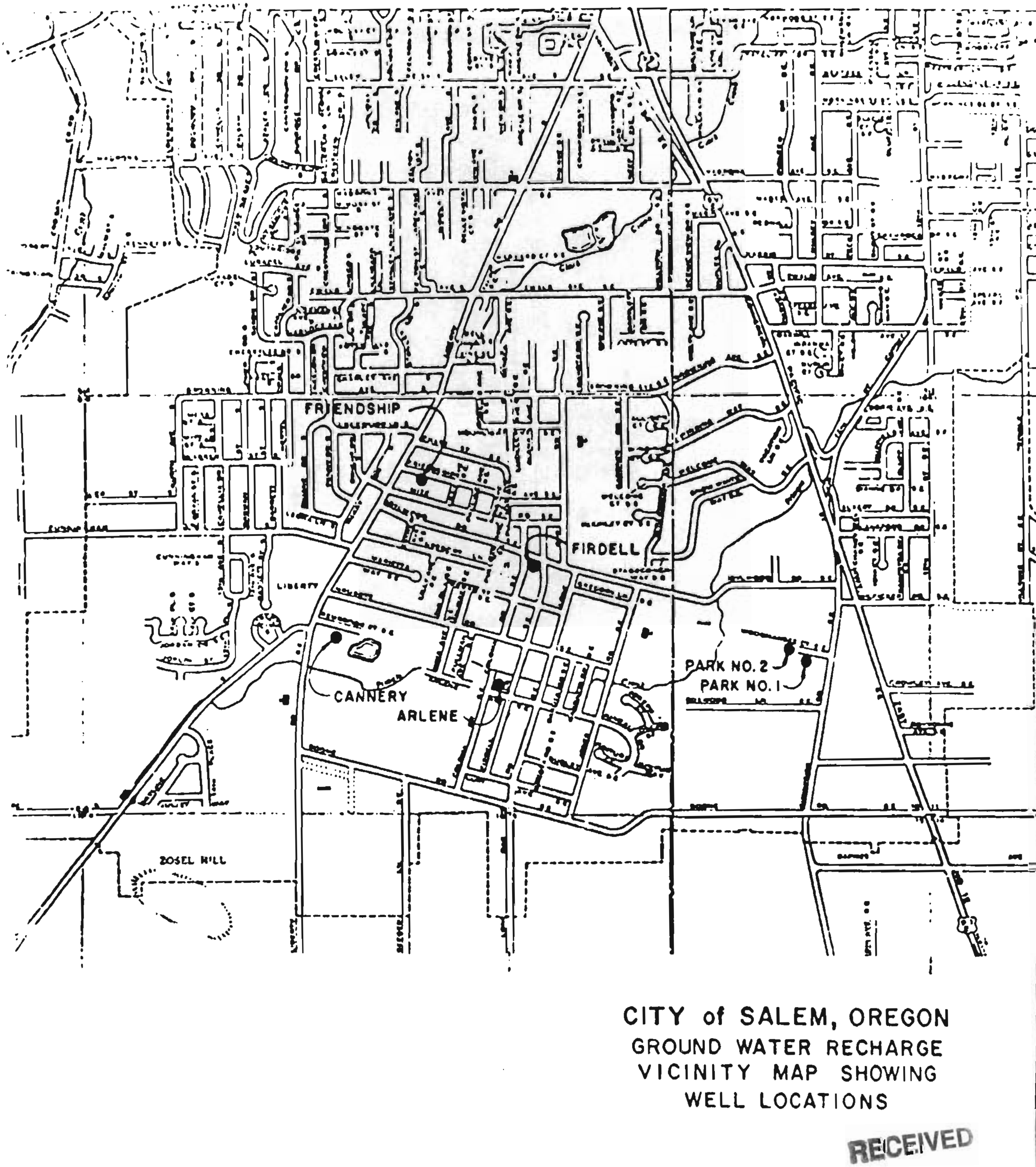
Dear Mr. Van Wormer:

In fulfillment of the engineering services to be performed as a part of our agreement dated March 2, 1977, the following is a letter report on observations and evaluation of the artificial groundwater recharge program undertaken by the City of Salem between March 1, and October 17, 1977.

Procedurally, the current program was based on the methods used in the artificial groundwater recharge research done in 1962 in the Salem Heights area by the Water Resources Division of the Geological Survey in cooperation with the then existent Salem Heights Water District.

The 1962 research program culminated in a Geologic Survey Water Supply Paper 1594-F entitled, "Hydrologic Conditions and Artificial Recharge Through a Well in the Salem Heights Area of Salem, Oregon." This report (Water Supply Paper 1594-F) goes into great detail describing existing facilities and procedural approach to artificial groundwater recharge in the Salem Heights area. With exception of the metering and piping installation at the Arlene Well, this letter report will not go into any detailed description of facilities which are so adequately covered in Water Supply Paper 1594-F. The well numbering system has been retained for identification purposes.

A vicinity map of the south Salem area, enclosed herein, shows the geographical relationship of the various groundwater wells which were a part of the current groundwater recharge program.



CITY of SALEM, OREGON
GROUND WATER RECHARGE
VICINITY MAP SHOWING
WELL LOCATIONS

Piping and metering equipment for groundwater injection into Park Well No. 2 were installed in 1962 as a part of the Geologic Survey program. After preliminary checking and adjustment of equipment and chemical analysis of city water and well water (see Exhibit A) artificial injection began on March 1, 1977 in Park Well No. 2.

Upon evaluation of the water distribution system and analysis of geologic conditions, a decision was made to use the Arlene Well as an injection well in conjunction with Park Well No. 2. Piping and metering equipment were subsequently designed and installed to facilitate injection of city water into the groundwater aquifer at the Arlene Well. Injection began at Arlene Well on April 4, 1977.

As indicated, Park Well No. 2 and Arlene Well were used as injection wells. The Fir Dell and Cannery Wells were used as principal observation wells. An attempt was made to use Park Well No. 1 and the Friendship Well as observation wells, however, there is some question as to the validity of the data derived from these sources.

The statistical data enclosed herein summarize the field data taken during the course of the recharge program.

Hydrographs of the recharge (injection) and observation wells are also enclosed with this letter. The hydrographs show the variation of the potentiometric water surface of the individual wells referred to in the statistical data.

The total gross volume of water injected into the recharge wells between March 1, and June 17, 1977, was 150,441,000 gallons, less surging to waste volume of 1,658,700, leaves the net volume of injected water 148,792,400 gallons.

Rise of the potentiometric water surface in the Park No. 2 and Arlene Wells, during the period of active injection was 67 and 51 feet respectively. The maximum rise in the potentiometric water surface in the Fir Dell and Cannery observation wells was 22 and 24 feet respectively.

Based on best information available, approximately 95,577,600 gallons of water have been recovered from the main aquifer. Individual totals of recovered water from the various wells are shown in the statistical data. Because of the extremely dry weather year, September, 1976 to September, 1977, it is considered opinion that natural recharge of the groundwater aquifer was not significant, and that the rise in water surface levels was due primarily to artificial recharge. Therefore, using the net volume

CITY OF SALEM, OREGON

ARTIFICIAL RECHARGE OF GROUNDWATER

STATISTICAL DATA

	Injection Wells		Observation Wells	
	Park No. 2	Arlene	Fir Dell	Cannery
Static Water Level Prior to Recharge March 1, 1977 (Ft Below Ground Surface)	245	321	258	328
Recharge (injected) 3/1/77 to 6/19/77 Volume: (Gal)				
Gross	100,110,000	50,341,100	——	——
Net	99,666,200	49,126,200	——	——
Surging Volume to Waste (Gal)	443,800	1,214,900	——	——
Net Recharge Duration (Hrs) 3/1/77 to 10/17/77	2,442	1,678	——	——
Total Rise in Water Surface (Ft) 3/1/77 to 6/17/77	67	51	22	24
Average Rate of Recharge (Injection - Gal/Min)	680	500	——	——
Average Specific Capacity GPM/Ft of Rise	10.1	9.8	——	——

WATER RECOVERED FROM AQUIFER BETWEEN 6/17/77 and 10/17/77

Well	Gallons Recovered
Park No. 2	36,346,700
Arlene	1,768,500
Friendship	15,359,400
Cannery	42,103,000*

Total 95,577,600

* Through the end of September, 1977

of injected water, 148,792,000 gallons, and the recovered water volume of 95,577,600, the percentage of recovered water through the end of September, 1977, would be approximately 64 percent. Analysis of the water levels shown on the hydrographs indicates that at Park Well No. 2, Arlene and Fir Dell Wells, the water surface elevations are still, as of October 17, 1977, considerably higher than the static water levels found prior to start of recharge on March 1, 1977.

The following tabulation entitled, "Gradient of Water Surface," converts depth to water to actual datum elevation (USGS datum) based on established ground surface elevation at the individual wells:

Gradient of Water Surface

		Depth to Water (ft)			Elevation of Water Surface		
Well	Ground Elevation	Static	Min.	Max.	Static	Min.	Max.
Park No. 2	386	245	178	274* 232(+)	141	208	112* 154(+)
Arlene	429	321	270	312	108	159	117
Fir Dell	421	258	236	246	163	185	175
Cannery	465	328	304(x)	428*	137	161	37*

*Pumping level
+Sept. 1, 1977 after conclusion of summer pumping of Park Well No. 2
xJuly 14, 1977 just prior to start of Cannery Well.

From the relative minimum elevations of the water surface it can be seen that the gradient slopes toward the Arlene Well prior to starting of Park Well No. 2 and the Cannery Wells. Under pumping conditions, as was the condition of the Cannery Well on October 17, 1977 the gradient was obviously sloping toward the Cannery Well.

As indicated in the Geologic Survey Water Supply Paper 1594-F, the main aquifer appears to be confined in nature. Therefore, it would seem reasonable to expect, under normal conditions, that nearly all water injected into the main aquifer, with exception of water molecularly locked or bound in the intricacies of the rock formation could be expected to be recovered.

Chemically, prior to mixing, the water quality of both the injection (city) water and well water appeared to be good as can be seen from the Chemical Analysis, Exhibit A.

Exhibit B presents a detailed chemical analysis of waters recovered from Park Well No. 2, Arlene and Friendship Wells between 7/22/77 and 8/29/77. These analyses represent the mixed character of the water. The mixed quality also appears to be satisfactory.

Exhibit C presents in tabular form the variability of solids content of both injection and mixed waters. During the recharge process, reversal of flows in the distribution system piping delivering water to the injection wells and in the fractured rock of the aquifer undoubtedly dislodged some sediments which were carried out of the wells during the pumping recovery of the mixed waters.

During the recovery process at the Park No. 2 and Arlene Wells, contaminants were found to be present in water samples taken from the mixed water. Through laboratory analysis, the contaminants were found not to be coliforms. It is possible that some form of ground contaminant was brought up with the mixed waters, although the specific nature of the contaminant was was not identified. After rigorous disinfection and flushing, both wells have been cleared of contamination and are now exhibiting satisfactory bacteriological results.

All in all, as was the conclusion in the 1962 Geological Survey Water Supply Paper 1594-F, artificial groundwater recharge of the south Salem basin appears to be feasible for storage of surplus water.

If artificial groundwater recharge is adopted as an ongoing program, several recommendations for improvements are obvious as a result of the current work recently completed, these recommendations are:

1. Consideration should be given to the installation of sediment traps at the injection wells.

2. Permanent air lines should be placed in all city wells within the study area boundaries. Although not as accurate as electronic probes or electric tapes, the air line, by virtue of ease of operation and convenience will provide satisfactory data.

3. If possible, all existing wells which penetrate the main aquifer within the confined boundaries of the aquifer should be used as observation wells. Information derived from these additional observation wells can be used to verify the gradient of the potentiometric water surface.

4. It is recommended that groundwater levels continue to be monitored and logged at least once a week for the balance of this weather year to determine the extent of natural recharge.

5. For any future recharge program, a better method of water quality analysis should be established to monitor significant constituents of injection water, well water, and recovered mixed water.

6. Data log forms for both injection and observation wells appear to be satisfactory and it is recommended that their use be continued.

If you have any questions or comments, please feel free to call us.

Very truly yours,

William C. Light

/ey

Enclosures