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ANALYSIS OF ICPP TANK FARM INFILTRATION

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EXECUTIVE SUMMARY

This report addresses water seeping into underground vaults which contain high-level liquid waste (HLLW) storage tanks at the Idaho Chemical Processing Plant (ICPP). Each of the vaults contains from one to three sumps. The original purpose of the sumps was to serve as a backup leak detection system for release of HLLW from the storage tanks. However, water seeps into most of the vaults, filling the sumps, and defeating their purpose as a leak detection system. Leak detection for the HLLW storage tanks is based on measuring the level of liquid inside the tank. The source of water leaking into the vaults was raised as a concern by the State of Idaho INEL Oversight Group because this source could also be leaching contaminants released to soil in the vicinity of the tank farm and transporting contaminants to the aquifer. This report evaluates information concerning patterns of seepage into vault sumps, the chemistry of water in sumps, and water balances for the tank farm to determine the sources of water seeping into the vaults.

The report addresses the eight underground vaults which contain the eleven 300,000 gal HLLW storage tanks. There are a total of eight vaults. Four of the tanks are contained in one large, square vault (713) that is divided into four chambers. Seepage into the vaults is not uniform. The four chambers of vault 713 show significantly more seepage than the other vaults in the tank farm. Vault 713 is located at the eastern end of the tank farm.

Water has seeped into the vaults since they were first constructed. The first vaults contained one small sump. In later vaults, the sumps were enlarged to hold more water. In the last two vaults constructed, three sumps were installed, one of which was specifically designed to collect seepage entering the vault from outside. The current rate of seepage is about 29,000 gal per year. This is slightly above historical trends, but is not very different than rates that have been observed over the past 25 years.

A review was conducted of all the potential sources of water responsible for the seepage. This included waste handling systems (such as waste transfer lines and leaks from the tanks), tank support systems (including cooling water and steam lines), man-made sources (such as potable water, raw water, sewage, and service waste lines), and natural sources (precipitation). For each possible source, characteristics describing the source were developed. Four characteristics were defined:

- **Pattern** – the pattern each source would produce in seepage was determined. Patterns were determined to be constant, precipitation related, seasonal, or random.
- **Chemistry** – the chemical signature of the sources were evaluated to determine if there were chemicals that would uniquely identify sources.
- **Location** – the spatial relation and proximity of sources to vaults were determined.
- **Volume** – the potential volume of water a source could generate was evaluated and compared to the volume of seepage observed.

In addition to sources, pathways that water could take to enter the vault were developed. There were four possible pathways identified:

- **Through the roof** – most vaults have roofs constructed of beams and panels, with the potential for a crack in the seal between the panel and beam. This provides an

opening that water can seep through.

- Through the walls – water could seep through the wall of the vault if a perched water table developed at the sediment–basalt interface outside the vault. Many of the vaults are constructed of pillars and panels with joints between the panels.
- Along pipe encasements – pipe encasements drain to monitoring stations where releases from pipes can be detected. The monitoring stations then drain back to the vaults so that releases from the pipes are contained. Water entering the pipe encasements could flow to the monitoring stations and then to the vaults.
- Release within the vault – Some of the potential sources, particularly the support systems sources, could release directly into the vault and would not require a pathway into the vault.

Once the characteristics of the sources and pathways were determined, information about seepage into the sumps was compared to these characteristics.

One characteristic of seepage is the pattern the seepage displays over time. Continuous seepage would suggest a constant source such as a leak from a pipe that always carried water. Seepage that increased in the spring would suggest a relation to precipitation. Seasonal variations would be expected for a precipitation–related source as summer evaporation dried out the soil. The dry soil would hold onto the precipitation, decreasing the precipitation–seepage response in the summer. Some sources might also be seasonal, such as watering the lawn in back of CPP-699. Finally, many of the sources would produce a random pattern in seepage, with occasional leaks or releases.

To evaluate the patterns in seepage, a least squares multiple regression approach was used to fit a model equation to the seepage data. Data used in the analysis consisted of the inches of water seeping into each vault per month. The time period used in the analysis was January 1989 through June 1993. For most vaults, only one sump was analyzed. This was because the second sump showed either no response to seepage, or because both sumps showed parallel response. Three vaults were not analyzed (780, 781, and 782) because there was so little seepage into these vaults that patterns could not be meaningfully determined. For two of the chambers in vault 713 (713/189 and 713/190), two sumps were included in the analysis.

The regression model showed that all vaults analyzed have a significant contribution from precipitation. This consisted of a precipitation response coefficient and a seasonal cycle which modified the precipitation response. The cycle reached a maximum in the spring (about April) and reached a minimum in the early fall when soil was driest. For most of the vaults, spring recharge was the only source of seepage into the vaults. This could be seen in cumulative seepage plots with sharp increased between March and June each year, and no seepage in the remaining months of the year.

For the sumps in vault 713, however, the pattern of seepage was different. These sumps still demonstrated a significant precipitation response coefficient, but the seasonal cycle was different. The seasonal cycle reached a peak in about June or July. These vaults also showed a significant constant seepage term. One method of producing the observed pattern of seepage in these vaults would be to combine two seasonal cycles: one related to precipitation/evaporation and peaking in April; and one peaking in August and September and related to lawn watering. The sum of the two

cycles would produce a third cycle with a maximum intermediate between the two (ie June or July). The summation would also result in a non-zero value for constant seepage. The constant would represent the average seepage over the course of an annual cycle and not necessarily a constant source.

The second characteristic of sump seepage was the chemical composition of the water. Only two samples were collected from sumps in the tank farm. These samples were collected from the cold sumps in vault chambers 713/189 and 713/190, the two that showed the most influence from non-precipitation related seepage. Therefore, these were the most important sumps for water chemistry data. Other sumps require heavy equipment to remove covers to access ports and were not sampled. The volume of water collected was very small because of the difficulty in sample collection, and therefore detection limits for analytes were very high. Conclusions based on the water chemistry, are therefore somewhat uncertain. Water samples were also collected from the raw water system and the potable water system at CPP-699. Both raw and potable water are pumped from the Snake River Plain aquifer, and have essentially identical water chemistry. The water chemistry of the sumps was also similar suggesting a common, external source.

Simple mixing models were used to determine if sump water chemistry could be related to the mixing of precipitation or aquifer water with high-level liquid waste. Mixing ratios for different species were very different indicating that simple mixing could not explain the water chemistry. There was also insufficient chromium in the sump water for the cooling water to be the source.

Chloride and sulfate had similar concentrations in raw/potable water and in the sump water. These are relatively conservative species without many sources or sinks in soil. This similarity suggests that water pumped from the aquifer was the source of water to the sumps. However, potable water, raw water, lawn watering, and fire water are all derived from the aquifer, and therefore have similar chemistry. Some species showed different concentrations than in the aquifer. A geochemical evolution model is proposed that involves dissolution of calcite from the soil, ion exchange of calcium for sodium, and leaching of nitrate and potassium added to the lawn in back of CPP-699 as fertilizer.

The locations of pipelines carrying aquifer water were identified. There are potable water lines, raw water lines, and fire water lines all running near the east end of the tank farm.

The volume of water entering the tank farm from different sources was evaluated. Based on the regression equations, an estimated annual contribution from precipitation was calculated to be 12,170 gal per year, or 41% of the total. The estimated contribution from the constant source was calculated to be 13,950 gal per year or 47% of the total. The remaining 12%, or 3,560 gal per year is from miscellaneous sources.

Volumes of water that could be released from all of the sources were evaluated. Many of the sources can only release a few to a few hundred gallons. Therefore, these sources cannot be a major contributor to seepage. However, many of these small sources (such as leaky steam valves, leaks from valve seals in waste transfer lines) do contribute to seepage periodically. The volume of water available from precipitation, after adjusting for evaporation, is 104,700 gal per year. The estimated volume of water available from lawn watering is 540,000 gal per year.

Pathways for water to enter the vault were also evaluated. There is a network of screened observation wells completed at the interface between the surficial sediments and the underlying basalt. This interface is at a depth of about 50 ft below land surface. The vaults are constructed on basalt,

and therefore this is also the depth to the bottom of the vaults. The screened observation wells have been monitored for water periodically since 1972. The wells are dry essentially all of the time. In spring during very wet years, such as 1993, water has been detected in some of the wells. Excavations into the surficial sediment and drilling to the top of basalt for sampling projects have not encountered water-saturated soils. Therefore, no saturated perched water table exists at the sediment-basalt interface. Without saturated conditions existing outside vaults, there is no driving force to move water through the walls of the vaults and seepage through the walls cannot be the pathway into the vaults.

In November of 1973, vault 713/190 was entered to investigate the source of water seeping into the vault. The report of that entry indicates that water was dripping down through the joints between the ceiling beams and panels. Therefore, ponding on top of the vault and seeping through the roof has been observed as an actual pathway for water to enter the vaults.

An additional pathway into the vaults is along the encasements for the waste transfer lines and the drain lines from the monitoring stations to the vaults. The line from the tank farm to the New Waste Calciner Facility passes directly beneath the lawn west of CPP-699. The line to the old Waste Calciner Facility passes under fire water lines and a large drainage ditch along the south east side of the tank farm. This pathway has not been confirmed, and would require investigation of the directions of flow and connections among the encasements, monitoring stations, and vaults.

Based on the analysis of seepage into tank farm vaults, the two most important sources of seepage are infiltration of precipitation and watering the lawn to the west of CPP-699. Infiltration of precipitation is a source of seepage to every vault except 781, which showed no seepage during the study period. The volume of water falling on the tank farm as precipitation is more than enough to provide the necessary volume of seepage water. The most likely pathway for precipitation to enter the vaults is seepage through the membrane at some of the many perforations made for pipes, risers, and valve boxes. Once on top of the vault, this water can seep through joints in the roof. Approximately 41 % of the water seeping into the vaults is from this source.

The second most important source of seepage for the tank farm is the watering of the lawn to the west of CPP-699. While the volume of water from this source is slightly larger than that from precipitation (47%) it only affects one vault. The pathway for water used on the lawn to enter the vault is not clear. For water from the lawn to get on top of the vault roof, it would have to move laterally some 30 to 40 ft with only 3 to 4 ft of vertical movement. This implies a very impermeable layer in the subsurface on which a perched water zone forms. Another possible pathway is along the pipe encasements and drain lines.

Analysis of ICPP Tank Farm Infiltration

1. INTRODUCTION

In the bi-monthly meeting between the U. S. Department of Energy, Idaho Field Office (DOE-ID) and the State of Idaho INEL Oversight Program held October 9th, 1992, the INEL Oversight Program raised a concern about water seeping into vaults at the high-level liquid waste (HLLW) tank farm at the Idaho Chemical Processing Plant (ICPP). The basis of this concern was that the HLLW tank farm safety analysis report indicates that seepage should be on the order of 50 to 100 gal per year.

"Historical data kept for the vaults pertaining to the volume of leakage from groundwater shows that a maximum of about 50 to 100 gal of water per year of in leakage can be expected."^a

Records maintained by ICPP operations indicate significantly more water is removed from the tank farm vault sumps each year, currently on the order of 29,000 gal per year. The INEL Oversight Program expressed a concern that this excess water could carry contaminants from the soil to the Snake River Plain aquifer (INEL Oversight Program 1993). A second concern was that the seepage into the vaults would prevent the use of the vault sumps as a leak detection system to monitor for releases from the HLLW storage tanks. Leak detection for the HLLW storage tanks, however, is based on measuring the level of waste inside the tank, not monitoring the vault sumps. Tank-level monitors do not indicate that HLLW is leaking from the storage tanks. A working group consisting of ICPP employees, the INEL Oversight Program, the U. S. Geological Survey (USGS), and DOE-ID is studying the water budget of ICPP and possible sources of water seeping into the tank farm vaults.

Review of past correspondence and other records maintained by ICPP indicates that the seepage into the vaults in the ICPP tank farm has been occurring for many years. ICPP monthly production reports from 1969 and 1970 report volumes on the order of 3,900 to 8,200 gal transferred from the vault sumps to the respective waste tanks in one month.^b Additional water, volume unrecorded, was pumped from cold sumps for tanks WM-189 and WM-190 to service waste. Estimates contained in internal ICPP correspondence in 1980 indicate from 20,500 to 25,500 gal per year were estimated to seep into tank farm vaults.^c Recorded volumes of water removed from all sumps in 1980 and 1981

a. *Aqueous Liquid Waste Management Safety Document*, WIN 107-4.2, Westinghouse Idaho Nuclear Company, Inc., p. 4.2-59, June, 1990.

b. C. B. Amberson written communication to F. R. Keller, *ICPP Production Monthly Report*, Idaho Nuclear Corporation, April 30, 1969; C. B. Amberson written communication to J. A. Buckham, *ICPP Production Monthly Report*, Idaho Nuclear Corporation, December 4, 1970.

c. A. B. Christensen written communication to B. R. Dickey, *Analysis of Water Ingress to Tank Farm Vaults*, Exxon Nuclear Idaho Corporation Inc., April 4, 1980.

were 9,350 gal and 19,680 gal respectively.^d The current rate of seepage into tank farm vaults is somewhat above historical trends, but is not very different than rates that have been observed and documented over the past 25 years.

1.1 Purpose and Scope

The purpose of this project is to determine the source(s) of water entering the tank farm vaults. This report describes the activities conducted to gather and analyze data to identify the sources. The project does not address monitoring of HLLW tank sumps to detect releases of HLLW from tanks. Leak detection for HLLW storage tanks is based on measuring the level of waste inside the tank. The scope of the project is limited to the 11 concrete vaults containing the 300,000 gal HLLW storage tanks at the ICPP tank farm.

1.2 Report Organization

The Background section of the report, Section 2, discusses the location, history, and previous investigations that have been conducted at the HLLW tank farm. The state of knowledge of the site is summarized and past investigations concerning seepage into sumps are described. A conceptual model for the tank farm is presented in Section 3. A number of possible sources for the water in the vault sumps are listed along with possible release mechanisms. The pathways along which the water could move to reach the vault sump are also presented. Section 3 discusses the sources, release mechanisms, and pathways with regard to the properties that could help evaluate the sources.

In Section 4, an analysis of water level records from tank farm vault sumps is performed to evaluate patterns in the water level records and to relate these patterns to sources of seepage. A model of seepage is presented and the sources of variation in the model described. The seepage records are presented along with the precipitation and recharge records. The analysis of the seepage records is explained, and finally the results of the analysis are discussed.

Results of chemical analysis of samples collected from tank farm vault sumps are presented in Section 5. Comparisons are made between the composition of water in the cold sumps for tanks WM-189 and WM-190 and water from a number of possible sources. Based on this comparison, a source is identified and geochemical processes affecting water chemistry are defined. Because of high detection limits for many analytes, this analysis contains many sources of uncertainty.

Section 6 describes assessments conducted to evaluate the movement of moisture in the vadose zone at the tank farm. The purposes of these assessments are to determine the quantity of water available for seepage into the tanks, the potential for precipitation recharging deep perched groundwater, and to evaluate the pathways water might take to enter the vaults. No additional data were collected for this part of the investigation. Assessments are based on a review of existing data and reports.

Section 7 summarizes the results of the investigation and presents the conclusions.

d. W. B. Palmer and G. W. Hogg written communication to E. M. Mansour, *Additional Tank Farm Vault Jets*, Exxon Nuclear Idaho Corporation Inc., March 17, 1982.

2. BACKGROUND

This section of the report discusses the location, history, and previous investigations that have been conducted at the HLLW tank farm.

2.1 Location and History

The HLLW tank farm is located within ICPP at the INEL in southeastern Idaho. The location of the ICPP is shown in Figure 2.1. The HLLW tank farm (Figure 2.2) is used to store radioactive liquid wastes that were generated during the reprocessing of spent nuclear fuel elements prior to the liquid wastes being converted to solids in the ICPP waste calcine facility. Construction at ICPP began in 1949 and the facility was operational in 1954. The HLLW tank farm has been in service since 1954 and the last tank was installed in 1962.

2.2 Facilities and Use

This section provides a brief summary of operations at ICPP and the primary facilities which generate wastes sent to the HLLW tank farm. The characteristics of the tank farm are described, and the general chemical and radionuclide composition of the waste streams is presented.

The ICPP was constructed to store and reprocess spent nuclear fuel from naval and research reactors. The primary purpose of the plant was to recover enriched uranium through dissolution of the fuel. In 1992, the mission of ICPP was changed to store and prepare spent fuel for final disposition. No fuel is currently being processed at ICPP. The plant includes a variety of laboratory and reprocessing facilities, process chemical storage facilities, process chemical and waste transfer pipelines, process waste storage and disposal facilities, office and maintenance facilities, and non-process waste disposal facilities. Plant activities require the use of numerous chemical and radioactive materials, resulting in generation of a variety of hazardous, mixed, and radioactive wastes.

Currently, no fuel is being reprocessed at ICPP. In the past, high-level-liquid wastes from the reprocessing facilities were sent directly to the tank farm for temporary storage. Approximately 200,000 gal/yr of HLLW were generated at ICPP when fuel was being processed (WINCO 1991). The tank farm consists of 20 storage tanks ranging in size from 18,400 to 320,000 gal. Liquid wastes are stored in the tank farm until the waste can be converted to solid form in the waste calcining facility. In addition to high-level-liquid waste, sodium waste from decontamination activities is also sent directly to the tank farm.

2.2.1 HLLW Tank Farm

The object of this investigation is the HLLW tank farm at ICPP. The tank farm receives liquid radioactive wastes for temporary storage until the wastes can be solidified in the waste calcine facility. The tank farm consists of a number of stainless steel storage tanks with capacities ranging from 18,400 to 320,000 gallons (Figure 2.3). Five tanks are located in a vault at the north end of CPP-604. The floor of this vault rests on basalt, 42 ft below land surface (bls). Three of these tanks (WM-100, WM-101, and WM-102) are used when waste streams need to be segregated.

FIGURE 2.2
LOCATIONS OF PRINCIPAL ICPP FACILITIES
 WINCO/PERCHED WATER SUPPORT/ID

Golder Associates

The fourth tank in the CPP-604 vault (WL-102) serves as a collection and feed tank for the PEW evaporator system. One tank in the CPP-604 vault (WL-101) is used to store PEW evaporator bottoms.

Four underground tanks (WM-103 through WM-106) were constructed in concrete basins, open at the top, rather than in vaults. Because the basins could fill with infiltration, and therefore have no capacity to retain a leak from the tank, they are not used. The remaining 11 tanks each have a capacity of approximately 300,000 gallons and are used to store the bulk of the liquid wastes. The stainless steel tanks are contained in underground concrete vaults (Figure 2.3). Vaults numbered 780 through 786 contain tanks numbered WM-180 through WM-186. Tanks numbered WM-187 through WM-190 are contained in vault 713. The tops of the tanks are approximately 10 ft below land surface (bls), with their bases located approximately 50 ft bls. In 1977, the tank farm was graded to promote drainage and covered with a synthetic membrane to inhibit water infiltration. The membrane is covered by approximately 6 in. of gravel.

2.2.2 Vault and Tank Construction

The vaults vary in details of design and construction. The general configuration of the vaults and tanks, however, share many similarities. A general drawing of the vault and tank construction details is shown in Figure 2.4. Vaults 780 and 781 are made of cast-in-place concrete and are octagonal in shape. The roofs of these vaults are different than the roofs of the other vaults. Vaults 780 and 781 have hunched roofs consisting of a 1.25 ft thick concrete slab supported by the hunched roof girders. Vaults 782 through 786 are constructed of pre-cast concrete columns and panels. The seams between the columns and panels and the panels and the floor are sealed with grout. The remaining tanks, WM-187 through WM-190, are enclosed with a single, rectangular, continuous pour concrete vault (713) with partitions separating the tanks. All of the vaults are constructed on 2.5- to 3-ft thick concrete slabs placed directly on bedrock. The walls range in thickness from 6 in. for the pillar and panel vaults, to 42 in. for the rectangular continuous-pour concrete vault. The roofs of vaults 782 through 786 and vault 713 consist of concrete panels resting on concrete beams which extend across the vault (Figure 2.4). Tanks in vaults 713 and 782 through 786 are placed on sand pads to distribute the load on the bottom of the tank.

The liquid-waste tanks are 50 ft across by 32 ft high. All the tanks are built of stainless steel. Most tanks contain cooling coils to carry away the heat generated by radioactive decay within the tanks. The composition and volume of waste within the tanks changes depending on fuel reprocessing and waste calcining activities. In the past, waste inside the tanks consisted mainly of solutions remaining from the dissolution of spent nuclear fuel. The solutions were very acidic, containing nitric, sulfuric, and hydrofluoric acids. Solutions also contained high concentrations of fission products (particularly Cs-137 and Sr-90), uranium isotopes, and transuranics (plutonium, neptunium, and americium). Solutions are also high in heavy metals, such as mercury and cadmium (Tables 2.1 and 2.2). Most of the fuel reprocessing wastes have been calcined, and the remaining HLLW in the tank farm is primarily sodium waste.

2.2.3 Vault Sumps

Each vault has from one to three sumps to collect any liquid which enters the vault. A list of vault sumps and their characteristics is provided in Table 2.3. Liquid levels in the sumps are monitored and if the level rises above the alarm level within a vault, the liquid is removed by jetting with a steam or air line. All four chambers of vault 713 contain two hot sumps where liquid is collected that

may enter the vault or come from the sand pad beneath the tanks. The sand pad is held in place by a four-in. high curb with weep holes that drain from the sand pad to a drain trench that drains to one of the two hot sumps. The two eastern chambers of vault 713 (for tanks WM-189 and WM-190) also contain a 36 in. by 60 in. cold sump that has a depth of 9 ft. This sump is designed to collect liquid that enters the vault outside of the tank area. The area that drains to the cold sump is separated from the drain trench to the hot sumps by a six-in. high curb.

Between June 1990 and April 1993, an average of 2,473 (Table 2.4) gallons of water per month were jetted from the tank farm vaults. The distribution of seepage into tank farm vaults is not uniform. Most seepage occurs at the eastern end of the tank farm into sumps in vault 713 (Table 2.4). Figure 2.5 shows the average annual volume of water jetted from the sumps between 1990 and 1993. Liquid levels in the vaults have been allowed to rise above the sump into the vault before jetting (the alarm level is generally higher than the weep holes from the vault sandpad to the sump). The only concern limiting the maximum liquid level in the vault is that if the level in the vault is higher than the level in the tank, the tank could float. A liquid level above the sump is generally indicated by both sumps within a vault showing simultaneous and parallel level changes from seepage or jetting.

FIGURE 2.4
**DIAGRAM OF A TYPICAL
 HLLW STORAGE TANK**
 WINCO/PERCHED WATER SUPPORT/ID

Table 2.1 Typical chemical composition of high-level-liquid waste streams.

Parameter	Waste stream		
	Nonfluoride ^a (moles/L)	Fluoride-bearing ^b (moles/L)	Sodium-bearing ^c (moles/L)
Hydrogen (H ⁺)	1.0-2.2	1.5-2.0	0.1-1.6
Nitrate	3.2-4.6	2.4	4.3-5.2
Fluoride	T ^d	2.5-3.6	T
Sulfate	0.01	T	0.04-0.06
Chloride	T	T	0.03
Boron	T	0.2	0.005-0.02
Cadmium	T	0.1	T
Mercury	0.018	T	T
Chromium	0.03	T	T
Zirconium	T	0.45	T
Aluminum	0.2-1.0	0.7	0.3-0.5
Sodium	0.004-0.007	0.03	1.6-2.4
Potassium	T	T	0.2

a. From dissolution of aluminum and stainless steel clad fuels.

b. From dissolution of zirconium clad fuels.

c. From concentrated PEW evaporator bottoms.

d. Trace (<0.1 wt%)

Table 2.2 Typical radionuclide composition of high-level-liquid waste streams.

Parameter	Waste stream			
	Half life (yr)	Nonfluoride ^a (mCi/L)	Fluoride- bearing ^b (mCi/L)	Sodium- bearing ^c (mCi/L)
Co-60	5.27	0.51	1.3	0.01
Sr-90	29	522	800	91
Ru-106	1.02	31	76	4
Sb-125	2.76	T	27	1.3
Cs-134	2.065	17	180	0.7
Cs-137	30.17	550	833	100
Ce-144	0.78	200	710	1.2
Eu-154	8.5	495	13	0.3
H-3	12.32	21	0.4	0.07
	(yr)	(mg/L)	(mg/L)	(mg/L)
U	4.46x10 ⁹ (U-238)	0.5	0.5	10
Pu	87.74 (Pu-238)	1.0	1.0	1.0

a. From dissolution of aluminum and stainless steel clad fuels.

b. From dissolution of zirconium clad fuels.

c. From concentrated PEW evaporator bottoms.

d. Trace (<0.1 wt%)

Table 2.3 Characteristics of tank farm vault sumps^a

Sump	Length (in.)	Width (in.)	Depth (in.)	Alarm level (in.)	Volume (gal)	Jets to
180 S	24	24	48	32	120	WM-181
181 S	24	24	48	32	120	WM-180
182 N	12	12	12	15	7.5	WM-182
182 S	12	12	12	15	7.5	WL-102/133 ^b
183 N	12	12	12	15	7.5	WM-183
183 S	12	12	12	15	7.5	WL-102/133
184 N	12	12	12	15	7.5	WL-102/133
184 S	12	12	12	15	7.5	WM-184
185 N	12	12	12	15	7.5	WM-185
185 S	12	12	12	15	7.5	WL-102/133
186 N	12	12	12	15	7.5	WM-186
186 S	12	12	12	15	7.5	WL-102/133
187 N	12	12	12	15	7.5	WM-187
187 S	12	12	12	15	7.5	WL-102/133
188 N	12	12	12	15	7.5	WL-102/133
188 S	12	12	12	15	7.5	WM-188
189 C	36	60	108	50 ^c	1,010	WL-102/133
189 N	12	12	36	40	22.5	WM-189
189 S	12	12	36	40	22.5	WM-189
190 C	36	60	108	50 ^c	1,010	WL-102/133
190 N	12	12	36	40	22.5	WM-190
190 S	12	12	36	40	22.5	WM-190

a. Characteristics of Tank Farm Sumps from Attachment A to Chemical Plant Operating Procedure 4.3.5.5, WINCO, August 4, 1993.

b. Starting in 1994, WL-102 will no longer be used and these sumps will jet to WL-133.

c. HI-HI alarm point for sumps 189 C and 190 C is 90 in.

FIGURE 2.5
 AVERAGE ANNUAL VOLUME OF WATER
 JETTED FROM VAULTS BETWEEN
 JUNE 1990 AND APRIL 1993
 WINCO/PERCHED WATER SUPPORT/ID

Golder Associates

Table 2.4 Total volume of water jetted from tank farm sumps between June 1990 and April 1993.

Sump	Gallons
180 S	0
181 S	0
182 N	0
182 S	2,900
183 N	0
183 S	0
184 N	0
184 S	0
185 N	0
185 S	4,092
186 N	0
186 S	4,791
187 N	0
187 S	15,090
188 N	15,253
188 S	0
189 C	12,707
189 N	1,695
189 S	16,479
190 C	11,186
190 N	2,156
190 S	200
Total	86,549
35 Month Average	2,473

2.2.4 Waste Transfer Systems

Liquid wastes from the various plant areas at ICPP are transferred to the tank farm through underground, stainless steel lines. HLLW and intermediate-level liquid waste transfer lines are separate, and are only used for the waste type specified. Transfers are initiated by airlift or steam jet. HLLW is either transferred directly to one of the 300,000 gal storage tanks, or is directed to tanks WM-100 through WM-102 for temporary storage. Concentrated PEW evaporator bottoms are directed to tank WL-101 for temporary storage then transferred to one of the 300,000 gal storage tanks.

All buried lines that contain high- and intermediate-level radioactive waste are enclosed in pipe encasements. Three types of pipe encasements are used at the tank farm: split tile, stainless-steel-lined concrete troughs, and double-walled stainless steel pipe. Transfer lines between storage vessels WM-180, WM-181, and the storage vessels in the CPP-604 tank vault (WM-100 through WM-102) are encased in split tile. All split-tile encased lines are scheduled to be replaced in the next few years. Transfer lines within the tank farm and between the tank farm and the NWCF are of the stainless-steel-lined trough and dual-walled stainless-steel pipe construction (Figure 2.6). Encasements drain to valve boxes where radiation monitoring can detect releases from the pipes to the encasement. Drain lines from the valve boxes are then routed to the tank farm vault sumps or to the CPP-604 vault.

2.3 Previous Investigations

There have been a number of previous investigations at the HLLW tank farm to evaluate water seepage into the HLLW vaults. This section summarizes those previous investigations and what is known about water movement in the surficial sediments within the tank farm.

2.3.1 Shallow Perched Water Monitoring

In September 1973, ten monitoring wells were drilled by the U. S. Geological Survey (USGS) at various locations in and around the ICPP tank farm as part of an effort to learn how water was entering the vaults*. The holes were drilled to bedrock and cased with 2 in. diameter aluminum pipe. The bottom 6 ft of pipe were screened to permit shallow perched water to enter the observation well. These wells were designated A-40 through A-49 and are referred to in this report as screened observation wells.

In September 1975, ten additional screened observation wells were drilled to extend the monitoring network to the older part of the tank farm. These wells are designated A-50 through A-59. No information concerning the findings of these drilling efforts could be found in USGS reports written about the time these wells were installed (Barracough and Jensen 1976; Barracough et al. 1981; Robertson et al. 1974). Over the years, most of these wells have been destroyed, and only eight screened observation wells remain (A-44, A-45, A-46, A-48, A-49, A-50, A-52, and A-56) (Figure 2.7). These wells have been monitored periodically by Westinghouse Idaho Nuclear

e. R. E. Commander, *Investigation of Tank Farm Soil Contamination Discovered September 1975*, Significant Operating Occurrence Report (SOOR) 75-27, November 1975.

a. Stainless-steel-lined concrete encasement

b. Double-walled stainless-steel encasement and support

FIGURE 2.6
CROSS SECTIONS OF TYPICAL
WASTE LINE ENCASEMENTS
WINCO/PERCHED WATER SUPPORT/ID

FIGURE 2.7
**TANK FARM OBSERVATION
 WELLS LOCATION MAP**
 WINCO/PERCHED WATER SUPPORT/ID

Golder Associates

Company, Inc. (WINCO) following WINCO Standard Operating Procedure (SOP) S.3.26 "Tank Farm Subsurface Contamination Monitoring." Review of unpublished WINCO records for these wells indicates that the wells have been dry since 1979. The most recent sampling was conducted in May 1993, after a year of high snowfall and above average spring precipitation. Of the screened observation wells tested, only A-52 contained water; the other screened observation wells were dry. Therefore, there appears to be at best, a very limited shallow perched water zone within the tank farm boundaries, and only when recharge is above average.

2.3.2 Tracer and Moisture Flux Studies

A study was conducted in the summer of 1981^f to evaluate seepage from nearby sewer lines, infiltration of precipitation, and vapor condensation as sources of tank seepage. The first experiment consisted of spreading 50 gal of water containing 20 lbs of fluorescein dye along the eastern border of the tank farm just outside the limit of the impermeable membrane. Design drawing 1578 CPP 304C-3 shows the membrane to extend about 22 to 24 ft beyond the edges of vault 713. The dye was spread on April 30, 1981. Sump samples were collected from cold sumps for tanks WM-189 and WM-190 as shown in Table 2.5. Fluorescein dye was detected in the July sample from sump 189 C and the September sample from 190 C at extremely low concentrations. Therefore, water from beyond the margin of the impermeable membrane can reach the tank vaults. Samples from the vaults were also analyzed for coliform bacteria as an indicator of sewage contamination. No coliform bacteria were detected.

The second experiment consisted of constructing a solar still just north of the tank farm. Water was collected from the still periodically between July 9, 1981 and September 3, 1981 and the volume of water measured. The volume of water collected was compared to the volume of water needed to provide 4,500 gal/yr of seepage into the tank farm vaults. Barometric pressure fluctuations were compared to the moisture flux to see if pumping of air into and out of the ground by barometric pressure changes affected the flux. The maximum water flux recorded was $2.9E - 4$ gal per hour of daylight per ft² of ground surface. No average flux was given but the author indicated that the flux rate was often near zero. The rate of accumulation necessary to generate 4,500 gal/yr was calculated by the author to be $2.7E - 4$ gal per hour of daylight per ft². Changes in barometric pressure could not be correlated to variations in moisture flux. However, moisture flux was heavily correlated to times of precipitation.

The conclusion drawn by the investigator was that the primary source of water seeping into the tank vaults was precipitation. Precipitation collected in drainage ditches surrounding the tank farm moved laterally at least 20 ft, and entered the vaults. The dye found in the vaults confirmed that this was taking place. Sewage was ruled out as a possible source of water.

f. F. N. McDonald written communication to G. G. Simpson, *Source of Water Ingress to the Tank Farm Vault Sumps*, Exxon Nuclear Idaho Company, Inc., November 2, 1981.

Table 2.5 Results of fluorescein dye tracer experiment.

Date	Sumps Sampled	Dye Detected
4/30/81	189 C, 190 C	no
5/15/81	189 C	no
6/25/81	190 C	no
7/21/81	189 C	yes (11 times detection limit)
9/9/81	190 C	yes (1.25 times detection limit)

3. CONCEPTUAL SITE MODEL

A conceptual model for the tank farm is presented pictorially in Figure 3.1 and as box and arrow diagram in Figure 3.2. A number of possible sources for the water in the vault sumps are listed along with possible release mechanisms. The pathways along which the water could move to reach the vault sump are also presented. This section discusses the sources, release mechanisms, and pathways with regard to the properties that could help evaluate the sources.

3.1 Sources

There are a number of sources that could contribute water to the tank farm vaults. These are generally divided into four categories.

3.1.1 Waste Handling Sources

Sources that are included in the waste handling category are:

- HLLW tanks
- Waste transfer lines
- Valves in waste transfer lines.

One possible source of water to the sumps is the high-level-liquid waste stored in the tank farm. This water could come from the tanks themselves, or from the waste-transfer lines or waste-transfer-line valves. Waste-transfer lines have leaked in the past, and the valve seals on the waste-transfer lines have been replaced because they leaked. Secondary containment for the waste-transfer lines drains to monitoring stations along the pipes. Most of these monitoring stations then drain to tank-farm vaults where the leaking water enters the vault sumps. This has happened in the past. There are currently no known leaking pipes or valves in the tank farm. All waste transfers within the tank farm are monitored for volume at the source and at the receiving end of the transfer to assure that the entire volume transferred is received. In addition to the water released by the leak, the pipe or valve must be decontaminated before repair. This usually takes about 100 gal of water which drains to the vault sumps.

The waste storage tanks are continuously monitored for water level inside the tanks. No leaks have been detected in tanks. The resolution of water level monitoring equipment in the tanks is ± 0.16 in. The tank diameter is about 50 ft, and so a change in volume of up to 200 gal might not be detected immediately. However, a leak would result in a trend in water level measurements that could be detected. Leaks from HLLW storage tanks could not generate the volume of water that is removed from the tank farm vaults without being detected by tank-level monitoring instrumentation.

HLLW contains very high levels of dissolved solids, high concentrations of radionuclides, and is extremely acidic. Typical waste compositions are shown in Tables 2.1 and 2.2. HLLW in water removed from vault sumps would contribute significant levels of contamination that would be detected by an analysis of water samples. However, because transfer-line valves have leaked in the past and through other mechanisms, some of the vault sumps are already contaminated. After the mid-1970s, radiation monitors were installed to pick up leaks in valve boxes.

FIGURE 3.1
SOURCES OF WATER THAT COULD CONTRIBUTE TO VAULT
SEEPAGE AND PATHWAYS WATER COULD TAKE INTO THE VAULT
 WINCOPPERED WATER SUPPORT/D

Golder Associates

FIGURE 3.2
**CONCEPTUAL MODEL OF WATER SOURCES AND
 PATHWAYS FOR THE HLLW TANK FARM**
 WINCO/PERCHED WATER SUPPORT/AD

In the late 1980s, new radiation monitors were installed. There have been two leaks since 1989 and both were picked up quickly. During maintenance of the transfer lines, approximately 100 gallons of water is flushed to the sumps causing contamination of the sumps. Some of this contaminated water may have entered the sand packs at the bottom of the vaults, and could be released slowly over a long period of time.

Two major transfers of HLLW from tanks to vaults occurred in 1962. Release of 31,700 gallons of radioactive first cycle aluminum nitrate-nitric acid raffinate waste from WM-187 to the concrete vault occurred on March 16 and 17, 1962^g. On March 19 and 20, 1962 a similar release occurred when 33,500 gallons of radioactive first cycle aluminum nitrate-nitric acid raffinate waste leaked to the vault surrounding WM-185. The mechanism of the transfer of radioactive liquid waste from the tank to the vault was determined to be siphoning through the vault-sump-jet piping to the tank. This condition was later corrected but this leakage left the vault and the sumps contaminated. The radiation detectors can still pick up transfers from these two sumps. Therefore, low levels of contamination in water samples collected from sumps would not necessarily provide evidence that waste tanks were leaking. Conclusions about the waste handling system as a source of water to the sumps must come from liquid levels in the tanks.

3.1.2 Support System Sources

There are two support systems that bring water into the tank vaults. These two support systems are the cooling water system to cool the waste tanks and the steam lines used to transfer waste and to purge the sumps. Many of the HLLW tanks contain cooling coils to reduce the temperature within the waste tanks due to radioactive decay. Currently, none of the tanks require cooling and so the system is not operating. Water is maintained in the system and monitored periodically for leaks. Water levels in the cooling water system have not declined indicating no leaks in the system. The cooling water is made up of treated water (demineralized water) with potassium dichromate maintained at 500 ppm to prevent corrosion.

Steam jets are used to transfer HLLW out of waste tanks and to transfer liquid from the vault sumps. Steam valves have leaked in the past resulting in steam condensate entering the vault sumps. This type of leak is very easy to detect because the leaking valve becomes hot from the leaking steam. Therefore, while this has been a source of some leakage to the vault sumps in the past, it is a source that is easily detected and corrected. Some steam condensate is released to the land surface near buildings 628, 635, and 636. The steam condensate is hot and generally evaporates quickly. Leakage from these valves is estimated to be on the order of 5 gallons per month.

3.1.3 Man Made Sources

Water is used for a variety of purposes at ICPP and transported about the plant in a number of distribution systems. Within the vicinity of the tank farm are a number of water systems:

- Service waste
- Potable water
- Sewage
- Fire water

g. J.W. Latchum, et al, Report to the Investigating Committee CPP Waste Tank WM-187 Leakage of March 17, 1962, Phillips Petroleum Company, April, 1962.

- Lawn sprinklers

Service-waste lines are used to transport industrial waste water from various processes to the percolation ponds at the south end of ICPP. There are two service-waste lines in the vicinity of the tank farm. One, very small line, carries steam condensate generated by the steam jets across the north end of the tank farm and connects to the main service-waste line along Beech Street, west of the tank farm. A second service waste line exits the north side of the PEW evaporator building (CPP-604), and flows west along the south side of the tank farm to Beech Street. The chemistry of the service waste is variable depending on the process. Service-waste lines generally are not pressurized, that is, they are only partially filled with water.

There is one potable-water line near the tank farm. This line feeds building CPP-699, immediately east of the tank farm. This is a fairly new line and is pressurized. The proximity of this line to vault 713, which has the greatest leakage, makes it potentially suspect. Potable water is pumped from the Snake River Plain aquifer.

Sewage from ICPP flows in ceramic-tile sewer lines to pump stations where it is pumped to a sewage treatment plant just east of ICPP. The nearest sewer lines to the tank farm are approximately 200 ft north of the northern tank farm boundary.

Fire-water lines run adjacent to the southeast corner of the tank farm. The line was pressure tested in 1991 and found to be sound. Fire water is provided from the raw-water system and pumped from the Snake River Plain aquifer.

Building CPP-699, just east of the tank farm, has a lawn that is watered. This lawn is about 45 ft east of the tank vaults. Discussions with WINCO personnel indicate the lawn is currently watered for seven minutes once a day, usually at night. The depth of applied water was measured and found to be 0.375 in. or 0.054 in./min. In dry years, the lawn is watered for 10 to 15 minutes twice per night. This watering takes place every night for seven nights a week. Given the surface area of approximately 2,970 ft² and approximately 0.375 in. of water being applied to the lawn surface, approximately 700 gallons of water is currently applied to this lawn per day or 21,000 gallons per month. In dry years, given 30 minutes of watering per night approximately 3,000 gallons of water are applied to the lawn per day. The lawn is watered from mid-April to mid-October. There was a leak in the sprinkler water line in the Spring of 1989. The line may have leaked for approximately one week prior to detection. The leak caused a large hole to develop in the lawn. Another leak developed in the end line in 1992, but was quickly detected and repaired.

3.1.4 Natural Sources

Water is added to the tank farm in the form of precipitation. The total amount of precipitation averages about 8.7 in. per year (Clawson et al. 1989). It should be noted that there is greater snow drifting on the east side of the tank farm. Therefore, total precipitation may be locally heavier in this area of the tank farm. The area of the tank farm is approximately 100,000 ft² giving a potential volume from this source of over 500,000 gal per year. Run-on to the tank farm from surrounding areas and buildings could increase this number significantly. This water could infiltrate into the soil, and then into the tank farm vaults. The tank farm is covered with an impermeable membrane. A dye tracer study in 1981 showed that lateral migration from drainage ditches surrounding the tank farm did reach cold sumps for tanks 189 and 190. Therefore, water can move laterally under the membrane to the vaults.

During November, 1973, the WM-190 tank vault was opened and entered for inspection of water sources entering the vault^h. The date of the entry is not given in the report. There were 1.02 in. of rain in the first two weeks of November, 1973 (Miller et al. 1990) with one storm of 0.48 in. on November 12th. Personnel performing the inspection noted that water was entering through tank riser structures and through the roof beam-to-wall joints. They did not observe any evidence of seepage through the vertical walls or through the wall-to-base slab joint. This inspection indicated that most of the seepage was dripping from inadequate roofing seals onto the top of the tank and then draining into the vault cold sump (190 C). The investigator indicated the seepage was due to water trapped on top of the roof beams. This inspection was performed prior to the installation of the impermeable membrane in the tank farm area. Precipitation may be entering the tank farm through breaks in the membrane for piping, vents, manholes, and other protrusions to the tank farm surface:

Roof drains from the northeast corner of building 699 drained onto the tank farm. These were changed in 1992 to drain to a north side drain and out to a drainage channel away from the tank farm.

3.2 Pathways

There are a limited number of pathways water can take to enter a vault. One pathway is through the drain lines for the pipeline secondary containment system. Secondary containment drains to sampling stations in valve boxes, and then to the vaults. This is to assure that any release from a pipe or valve is contained. Therefore, any water, from a pipe release or other source, that gets into the pipe containment system can drain into a vault. A few of the sources are internal to the vault and do not require a pathway.

Most of the sources are external to the vault, and water would have to pass through the vault wall or ceiling. The construction of most of the vaults provides a ready pathway through the vault ceiling. The ceilings (except vaults 780 and 781) consist of concrete slabs placed on T beams over the vault. Any water pooling on the concrete slabs could enter at the side of the slab where it contacts the T beam. Roof construction is compatible with this pathway for all vaults except 780 and 781. These two vaults have a different roof construction as discussed in Section 2.2.2. The hunched roof configuration would be expected to shed water rather than allow the water to build up on top of the roof.

Water has to get on top of the vault to enter through the ceiling. This pathway is therefore considered to require water in the shallow soil. If water infiltrates to deeper soils, then the only pathway into the vault is through the vault wall. A saturated zone of water would have to form adjacent to the wall to create a driving force to move water through the wall of the vault. Monitoring of screened observation wells in the surficial sediments since the early 1970s has shown that very rarely do surficial sediments become saturated. Excavations for construction and drilling to basalt in the tank farm have found moist sediments, but no saturated zones or perched water tables. Therefore, the most likely pathway for water to enter the tank is through the roof.

h. Allied Chemical Corporation, written communication, ECP Production Monthly Report No. 164, October 27 - November 26, 1973, December 5, 1973.

3.3 Evaluation of Sources and Pathways

Table 3.1 lists the sources, release mechanisms, and pathways for seepage into the tank farm. An evaluation of the sources and pathways is included in the table along with data needs to fully evaluate the source or pathway.

Table 3.1 Discussion of sources hypothesized to generate seepage into the HLLW tank farm vaults.

Source and Release	Hypothesis	Characteristics			
		Pattern	Chemical	Location	Volume
Valve seals in waste transfer lines leak to secondary containment	The seals in valves for the waste transfer lines are hypothesized to leak during waste transfers. Waste runs into secondary line containment, through valve boxes, and into vault sumps.	Occurs only when waste transfers take place. Tied to NWCF operations. Consider to be random over time.	Depends on waste transfer. Very high TDS and radionuclide concentrations. Tables 2.1 and 2.2 give typical values.	Any vault that receives input from secondary containment lines.	Uncertainty in transfer volume is $\pm 5\%$. Absolute volume depends on transfer volume. Even if leak doesn't reach vault, about 100 gal of water used to decon line before repair.
Waste transfer lines leak to secondary containment	A waste transfer line is hypothesized to have a small leak. The HLLW is released to the secondary containment, which drains through valve boxes to the vault sumps.	Occurs only when waste transfers take place into or out of the tank farm. Consider to be random over time.	Depends on waste transfer. Very high TDS and radionuclide concentrations. Tables 2.1 and 2.2 give typical values.	Any vault that receives input from secondary containment lines.	Uncertainty in transfer volume is $\pm 5\%$. Absolute volume depends on transfer volume.
HLLW tank leaks directly to a vault	It is hypothesized that a small leak exists in a stainless-steel tank containing HLLW. A small amount of waste leaks out over time depending on the level of the waste in the tank. As the tank is filled and emptied, the rate of this leak changes as a function of the hydrostatic head above the leak. If the hole in the tank is uncovered, the leak stops.	Depends on tank operating history. Assume fluctuation about an average continuous rate.	Depends on tank contents. Very high TDS and radionuclide concentrations. Tables 2.1 and 2.2 give typical values.	Could be any vault except 713/190 because tank 190 is empty.	Volume that could leak and not be detected is 200 gal. Greater than this would be detected by tank level monitoring.

Table 3.1 (Continued).

Source and Release	Hypothesis	Characteristics			
		Pattern	Chemical	Location	Volume
Steam valve leaks into vault or vault sump	The hypothesis is that a steam valve leaks resulting in condensate leaking into the vault or vault sump.	Leaking steam valves are readily detected during routine maintenance operations. Would not expect valve to leak undetected for long periods. Pattern would be random over time.	Steam would have no dissolved solids or radionuclides.	All vaults have steam lines for jetting sumps or tanks.	Leakage to vaults or tanks of up to 100 gal has occurred in the past.
Steam condensate is released to land surface over tank farm	Steam is used to jet waste from the tanks and to jet seepage from the vault sumps. Small amounts of steam are run through the lines continuously, and vented to the land surface on top of the tank farm.	The steam lines are shut off at times, but are usually left on. Input continuous.	Steam would have no dissolved solids or radionuclides. Could pick up small amounts of both infiltrating through surface soils.	Steam vents to the surface are located at CPP-628, CPP-635, and CPP-636. This could be a source for vault 713 (all four chambers) and vaults 782 and 783 next to CPP-628.	Volume of water at the surface is estimated to be 5 gal/month.
HLLW tank cooling water leaks to vaults	Most HLLW tanks contain cooling coils to remove heat generated by radioactive decay. Cooling water lines run through most of the tanks in the tank farm. A small leak is hypothesized to exist in a cooling-water line with water leaking into a vault.	Water is present in the lines all the time, even though the lines are currently not in use. A small leak would provide a continuous input.	Cooling water is demineralized water with 500 mg/L of potassium dichromate added as corrosion inhibitor.	Three tanks do not have cooling coils, 181, 184 and 186. Vaults 781, 784, and 786 could not have this source.	No historical data. System has pressure-drop alarm, so volume lost would be small.

Table 3.1 (Continued).

Source and Release	Hypothesis	Characteristics			
		Pattern	Chemical	Location	Volume
Service waste lines leak to surficial sediments	A small leak is hypothesized to exist in a service-waste line with the waste leaking to surficial sediments.	Seepage would be continuous on the time scale of a month.	Composition would be highly variable depending on waste stream.	Service waste lines run along the northern, the western, and the southwestern boundaries of the tank farm.	Volume highly variable depending on flow rate in pipe.
Potable water line leaks to surficial sediments	A small leak is hypothesized to exist in a potable-water line with the water leaking to surficial sediments. A small leak might go undetected, and create a continuous input to surficial sediments.	The seepage would be continuous.	The composition of seepage would be the same as potable water.	A potable water line runs to building CPP-699, immediately east of the tank farm.	A leak of any magnitude in this line would likely be detected due to wet soil above the leak (ie. like the leak near the cafeteria).
Sewage waste line leaks to surficial sediment	A small leak is hypothesized to exist in a sewage-waste line with the waste leaking to surficial sediments. The sewer lines are not pressurized, and a small leak could go unnoticed.	The input would be continuous.	The water would be high in TDS and organic carbon. Bacteria might also be present.	Sewage waste lines run past the west end of the tank farm and to the lift station north of the tank farm.	Volume highly variable depending on flow rate in pipe.
Fire water line leaks to surficial sediment	A small leak is hypothesized to exist in a fire-water line with the water leaking to surficial sediments. A small leak might go undetected, and create a continuous input to surficial sediments.	The input would be continuous.	The water would have the same composition as raw water.	A fire water line runs along the southeast boundary of the tank farm.	A leak of any magnitude would be detected by wet soil above the leak (ie. like leak in sprinkler line at CPP-699).

Table 3.1 (Continued).

Source and Release	Hypothesis	Characteristics			
		Pattern	Chemical	Location	Volume
Lawn sprinklers spray water on the lawn	The lawn west of CPP-699 is watered in the summer months. Water from the lawn sprinklers is hypothesized to infiltrate the ground and move laterally to the tank farm.	Watering the lawn would produce a seasonal pattern with a maximum in the late summer or early fall, and a minimum in winter.	The water would have the same composition as raw water.	Vaults at the east end of the tank farm would be most susceptible.	Volume of water to ground surface ranges from 150,000 to 600,000 gallons/month
Precipitation falls on tank farm and infiltrates through gaps in the liner and/or moves laterally from drainage ditches	Infiltration of precipitation falling on the tank farm can occur whenever the volume of water input by precipitation exceeds the storage capacity of the soil above the tank farm. Water is hypothesized to infiltrate around risers and through holes in the liner. Water may move laterally from drainage ditches adjacent to the tank farm.	Input would occur whenever there was significant precipitation. Low soil moisture conditions could affect this by intercepting the precipitation. Some seasonal component due to evaporation.	The water would pick up small quantities of dissolved solids and radionuclides in surface soils.	Any tank with risers and valve boxes on top would be subject to infiltration. Tanks with flat roofs would be more susceptible. Tanks at east end would be more susceptible because the tank farm surface drains west to east. Drainage ditches adjacent to east and southeast boundaries.	Average net recharge estimated between 0.4 in. and 2 in. per year. From 100,000 ft ² tank farm can have from 25,000 gal to 125,000 gal per year.

4. ANALYSIS OF PATTERNS IN TANK FARM SEEPAGE

In this section, an analysis of water level records from tank farm vault sumps is performed to evaluate patterns in the water level records and to relate these patterns to sources of seepage. A model of seepage is presented and the sources of variation in the model described. The seepage records are presented along with the precipitation and recharge records. The analysis of the seepage records is explained, and finally the results of the analysis are discussed.

The approach used for this analysis is a multiple regression fit of a model to the seepage into the tank farm sumps. A least squares fit is used to estimate parameters describing how the sources contribute to seepage. The period analyzed is from January 1989 through June 1993. This period of record has been computerized for ready retrieval of the sump water levels. The actual data to be analyzed consist of the total inches of water seeping into a vault sump during a one-month period.

4.1 Statistical Model for Seepage Into Tank Farm Vaults

This section discusses the mathematical equation that describes the relation between sources of water and seepage into the sump. The following two sections discuss the data that are used in the analysis. The conceptual model for tank farm vault seepage presented in Section 3 addresses a number of sources and pathways. The statistical model cannot address individual sources, but addresses patterns in seepage. The sources listed in Section 3 can be categorized as to the pattern in seepage that would be expected, and related to the observed patterns. Finally after all of the information is compiled, the most probable sources can be identified.

The sources and pathways for seepage into the tank farm vaults depicted in the conceptual site model (Figure 3.1) were reviewed to determine the types of seepage patterns that might be expected from the various sources. Four patterns were identified, and the sources identified as to which of the four patterns would be expected from that source. Table 3.1 lists the various patterns that each of the hypothesized sources is expected to have. The four patterns are continuous, precipitation, seasonal, and random.

- **Continuous** – This type of seepage indicates a constant flow of water into the vault throughout the year. Sources of seepage that could provide a continuous input to the vault are most likely leaks from pipes or valves that contain water year round.
- **Precipitation** – A sharp increase in seepage correlated to precipitation events has been noted in past WINCO reviews of seepage data.
- **Seasonal variation** – Precipitation falls throughout the year. Even in summer from 0.5 to 0.7 in. of precipitation are expected per month. However, for many of the sumps, seepage only occurs in spring. Seasonal effects, possibly related to drying out of the soil during the summer by evaporation, reduce the ability of precipitation to reach the vault sumps. Therefore, a seasonal component is added to the model. Other sources could also have a seasonal component such as watering the lawn behind building CPP-699.
- **Residual variation** – In addition to the three sources mentioned above, there may be additional sources of variation. Some of this could arise from non-repeated events, such as a short-term leak from a steam valve or the raw-water line. These short term

sources are identified as having a random pattern. In addition, there will be random fluctuations resulting from a myriad of causes that cannot be explained.

The overall model of seepage is therefore:

$$S = C_0 + C_1 Q^n + C_2 \sin\left(\frac{2\pi t}{12} + \alpha\right) + \epsilon$$

where:

S	=	Total monthly seepage (in.)
C_0	=	Constant monthly seepage
C_1	=	Response factor to recharge
Q	=	Recharge (in.)
n	=	Exponent for non-linear relation to recharge
C_2	=	Response factor to seasonal fluctuations
t	=	Time (months)
α	=	Lag time (radians)
ϵ	=	Residual variation

Some of these terms need some further explanation. The recharge component was considered to be potentially nonlinear. That is, there may not be a simple 1 to 1 relation between the amount of recharge and the amount of seepage. Small recharge events may not reach the vault because of soil moisture storage. For larger events, the percentage of recharge reaching the vault may increase as the total amount increases. Therefore, recharge was permitted to have an exponent different than one. After fitting data with a number of exponents, an exponent of 2 was found to provide the best fit for the most sumps. For three sumps, a slightly better fit was obtained by using a linear or cubic exponent. Because the improvement was small, all sumps were fit using recharge squared to provide comparability between sumps.

The seasonal variation is modeled using a sine wave. Monthly data are used, and the data therefore go through one cycle (2π radians) in 12 months. The cycle does not necessarily start at 0 in January, and so a phase shift angle, α , is included. For a seasonal cycle caused by evaporation drying of soil, it would be expected that the maximum of the cycle would be in the spring, and the minimum would be in the fall. If the cycle deviates from this expectation, then some other process may be influencing the seasonal cycle. For example, if watering the lawn behind CPP-699 provides significant seepage to a vault, then the maximum would occur in late summer rather than the spring.

4.2 Sump Water Level Data

Water levels in sumps are continuously monitored by ICPP. Since January 1989, this data has been recorded by a digital system that stores the information in a computer. The computerized records starting in January 1989 were retrieved and used in this analysis. Earlier records are available in tabular form in paper records. The past 4½ years was considered sufficient record length for the analysis. Therefore, no attempt was made to retrieve data from before January 1989. The study period used in this analysis is from January 1989 through June 1993, a period of 54 months.

4.2.1 Source of Data

Plots were generated of the sump water levels, and are attached to this report as Appendix A. For each sump, the total inches of rise for each month was measured off the graphs. The data analyzed are, therefore, the total monthly seepage into the sump in inches. Monthly seepage totals for the sumps analyzed in this project are shown in Table 4.1.

4.2.2 Discussion of Individual Vaults and Sumps

There is quite a bit of variation in the seepage patterns for different vaults. This section discusses the plots of the seepage and the relation between multiple sumps within a single vault. After reviewing the data, it was concluded that analysis of only one sump within a vault was necessary. The sump analyzed was the sump that was actively jetted to remove water. The second sump was either isolated from the active sump, and showed no activity; or was hydraulically connected to the active sump, and the data were redundant. The only exception to this was for sumps associated with tanks 189 and 190, where one hot sump and the cold sumps were analyzed.

4.2.2.1 Vault WM-780. This vault contains only one sump, WM-180 S. Review of records since January 1989 revealed that the only seepage into this vault occurred during the months of May and June 1993. The data would not provide a meaningful statistical analysis, and so no model fitting was performed with data from sump 180 S. A plot of cumulative seepage into sump 180 S is shown in Figure 4.1.

4.2.2.2 Vault WM-781. This vault contains only one sump, WM-181 S. Review of records since January 1989 revealed no seepage into this vault. The sump was not included in the analysis of seepage patterns because there were no data to analyze (Figure 4.1).

4.2.2.3 Vault WM-782. This vault contains two sumps, WM-182 N and WM-182 S. The northern sump jets back into the waste tank. Sump 182 S jets to the PEW evaporator building. Sump 182 N did not receive any direct seepage during the study period. The only time 182 N showed any change in water level was when water in sump 182 S rose above the top of the sump and flooded the bottom of the vault. There was a direct correlation between the water level in sump 182 S rising over the top of the sump, and the rise in sump 182 N. There was no seepage into sump 182 N.

A plot of cumulative seepage into sump 182 S is shown in Figure 4.4. The plot shows a series of steps with rapid increase in the spring of each year (January through April) and no seepage in the remaining months of the year. Seepage into vault 782 shows a clear relation to spring recharge. This vault was not included in the statistical analysis.

4.2.2.4 Vault WM-783. There are two sumps in this vault, WM-183 N and WM-183 S. The northern sump jets back into the waste tank. Sump 183 S jets to the PEW evaporator building. Neither sump was jetted during the study period. The fluctuation in water level of the two sumps was very similar throughout the study period. The water levels were, however, well below the top of the sump indicating that both sumps receive seepage at about the same rate. Because of the parallel behavior of the two sumps, only WM-183 N was included in the analysis.

Figure 4.3 shows a plot of cumulative seepage into sump 183 N during the study period. This sump also shows a general stair-step pattern, but not as extreme as for sump 182 S. Seepage does not occur every spring, and there are a number of periods of seepage between April 1991 and July 1992

Table 4.1 Monthly seepage into ICPP tank-farm-vault sumps.

	180 S	181 S	182 S	183 N	184 N	185 S	186 S	187 S	188 N	189 C	189 S	190 C	190 S
	(seepage in inches of water)												
Jan-89								0.9	0.5	78.4	1.9	5.6	
Feb-89			4.1	1.9				0.9	1.0	81.2	5.6	22.4	2.5
Mar-89			8.9	9.6	0.6	2.9	2.5	4.8	5.0	182.0	22.4	131.6	3.7
Apr-89				4.6		0.4		0.9	0.7	61.6	5.9	40.3	2.2
May-89						0.3		0.2	0.2	79.5	2.0	50.4	0.7
Jun-89						0.3		0.2	0.2	89.6	1.4	23.5	0.2
Jul-89						0.2		0.2	0.2	51.0	7.9	27.0	0.6
Aug-89						0.2		0.3	0.2	15.8	4.0	15.0	0.6
Sep-89						0.2			0.2	8.8	0.7	12.0	
Oct-89						0.2		0.1	0.2	13.2	3.3	13.8	1.3
Nov-89									0.1		1.6	15.6	
Dec-89										30.8	0.6	9.0	
Jan-90										58.8	5.3	12.6	0.9
Feb-90								0.7	0.8	63.8	7.0	15.1	0.9
Mar-90			7.0			1.7		2.0	2.0		10.6	25.2	0.9
Apr-90								0.3	0.2		4.4	20.2	1.8
May-90									0.2		1.8	33.6	0.9
Jun-90			2.0						0.2		8.8	46.2	1.8
Jul-90						0.4		0.6	0.3		3.1	18.2	0.6
Aug-90						0.3		0.3	0.3		2.3	21.6	0.9
Sep-90						0.3		0.4	0.1		1.1	20.2	0.3
Oct-90						0.2		0.1	0.3		11.2	16.8	0.7
Nov-90									0.1		17.9	16.8	1.7
Dec-90										7.8	6.7	17.3	
Jan-91										8.0	1.4	24.0	
Feb-91								1.2		36.0	2.3	17.6	
Mar-91			9.5	2.5	0.6	0.6	1.8	1.2	1.2		13.2	44.0	3.2
Apr-91				1.2	0.2	0.2	1.2	1.0	1.2		11.2	32.0	8.6
May-91			9.0	2.5	0.2	1.3	1.0	1.5	1.9		19.6	60.0	5.8
Jun-91			6.5	1.3		0.6	1.8	1.2	1.2		11.2	44.0	3.2
Jul-91						0.2	0.4	0.5	0.6		7.6	33.8	2.9

Table 4.1 Continued

	180 S	181 S	182 S	183 N	184 N	185 S	186 S	187 S	188 N	189 C	189 S	190 C	190 S
	(seepage in inches of water)												
Aug-91						0.2	0.1	0.6	0.6		3.0	36.4	0.7
Sep-91				2.3		0.2	0.1	0.4	0.5		4.6	17.7	0.4
Oct-91						0.2	0.1	0.1	0.5	6.4	2.4	20.8	0.7
Nov-91								0.1	0.3	8.0	8.5	19.5	
Dec-91								0.1	0.5		7.6	13.0	0.4
Jan-92									0.2	3.0	7.0	16.0	
Feb-92					0.3	0.2	1.5	0.7	1.0		6.0	12.0	0.7
Mar-92						0.3		0.3	0.8		4.5	9.0	1.0
Apr-92						0.1		0.3	0.3	9.0	6.8	8.0	0.5
May-92								0.2	0.3		6.5	11.4	0.7
Jun-92				2.0		0.8	1.1	0.8	0.5		8.0	28.6	1.5
Jul-92						0.3	0.4	0.8	0.5	93.0	5.3	19.0	2.2
Aug-92						0.3		0.2	0.4		2.7	10.2	0.6
Sep-92						0.2		0.3	0.1		1.8	14.3	0.3
Oct-92						0.1			0.1		0.7	13.6	0.3
Nov-92								0.1			0.7	13.6	
Dec-92								0.1			0.4	10.2	
Jan-93				1.7			0.9	1.0	1.0	6.0	1.3	8.9	
Feb-93			8.0	5.1	0.5	0.6	1.5	1.5	0.8	6.0	2.7	8.3	0.6
Mar-93			12.0	3.8	0.6	6.0	1.8	8.2	7.0	30.0	33.1	40.0	4.5
Apr-93			0.7			1.5		2.0	1.7	24.0	12.9	20.0	3.5
May-93	2.2		2.0	1.2	0.5	1.7	1.7	3.0	2.7	57.0	21.0	60.0	3.6
Jun-93	1.6		3.0	2.0	0.5	2.2	2.7	4.3	3.8	157.0	23.0	150.0	4.3
Total	3.8	0.0	72.7	41.7	4.0	25.1	20.6	44.6	42.4	1265.7	374.4	1445.3	73.4
Water level is in:	Sump	Sump	Sump	Sump	Sump	Vault	Vault	Vault	Vault	Sump	Vault	Sump	Sump

Shaded cells highlight periods when the water level rose above the top of the sump. Inches of infiltration are transformed to be equivalent to inches of rise in the sump using vault rating curves in Chemical Plant Operating Procedure 4.3.5.5.

FIGURE 4.1
**CUMULATIVE SEEPAGE INTO VAULT SUMPS FOR
 SUMPS WITH LOW SEEPAGE RATES**
 WINCO/PERCHED WATER SUPPORT/ID

FIGURE 4.3
 CUMULATIVE SEEPAGE INTO VAULT SUMPS FOR
 SUMPS WITH INTERMEDIATE SEEPAGE RATES
 WINCO PERCHED WATER SUPPORT/MD

FIGURE 4.4
 CUMULATIVE SEEPAGE INTO VAULT SUMPS
 FOR SUMPS WITH HIGH SEEPAGE RATES
 WINCO/PERCHED WATER SUPPORT/AD

FIGURE 4.5
CUMULATIVE SEEPAGE INTO VAULT SUMPS WITH
VERY HIGH AMOUNTS OF SEEPAGE
 WINCO/PERCHED WATER SUPPORT/AD

that are not correlated to spring recharge. The major periods of seepage, however, are related to spring recharge in 1989 and 1993.

4.2.2.5 Vault WM-784. This vault contains two sumps, WM-184 N and WM-184 S. The southern sump jets back into the waste tank. Sump 184 N jets to the PEW evaporator building. Sump 184 S did not receive any direct seepage during the study period. The amount of seepage into sump 184 N was very small, and the water level remained within the sump over the entire period. Seepage into sump 184 N was included in the pattern analysis. However, the data were very sparse, with only eight of 54 months resulting in any seepage.

Figure 4.1 shows a plot of seepage into sump 184 N. The stair-step pattern is again apparent with seepage occurring in four of the five springs during the study period. There was no seepage during the spring of 1990, nor during any other time of year.

4.2.2.6 Vault WM-785. The water level in vault WM-785 was above the top of the sumps for the entire study period. Therefore, the measured responses at both sumps, 185 N and 185 S, were identical. Because both sumps were measuring the same water level, only measurements from sump 185 S were analyzed for patterns. This is also the sump that was used to jet water from the vault during the study period.

A plot of cumulative seepage into sump 185 S is shown in Figure 4.2. This plot shows a much softer pattern than those discussed previously. While there is an abrupt increase in seepage each spring of the study period, seepage continues through the summer months. The cumulative seepage curve does not level off each year, indicating no seepage, until October or November.

4.2.2.7 Vault WM-786. There are two sumps in vault WM-786, WM-186 N and WM-186 S. Sump 186 S is used to jet water from the vault to the PEW evaporator. The water level in vault WM-786 was above the sumps for the entire study period, and so both sumps show identical water level response. Data from sump 186 S was used in the analysis of patterns. Data from sump 186 N were redundant.

A plot of cumulative seepage into sump 186 S is shown in Figure 4.2. The primary periods of seepage occur in the spring, with no seepage occurring during the spring of 1990.

4.2.2.8 Vault WM-713. This vault is the large, square vault divided into four smaller sections and housing four tanks. There are a total of ten sumps in vault 713. Two sumps each are associated with tanks WM-187 and WM-188. Tanks WM-189 and WM-190 have two hot sumps and one cold sump each.

The two sumps associated with tank WM-187, WM-187 N and WM-187 S, showed parallel water level response throughout the study period. The water level remained above the top of the sumps throughout the period. Sump 187 S is used to jet water from the vault to the PEW evaporator facility. Water levels from sump 187 S were used in the analysis of seepage patterns. Seepage into sump 187 S is illustrated in Figure 4.3. Seepage into sump 187 S shows the muted stair-step pattern, with increased infiltration in the spring, but continued infiltration throughout the year. Only in the middle of winter (December and January) did seepage to sump 187 S stop.

The two sumps associated with tank WM-188, WM-188 N and WM-188 S, showed parallel water level response throughout the study period. The water level remained above the top of the sumps

throughout the period. Sump 188 N is used to jet water from the vault to the PEW evaporator facility. Water levels from sump 188 N were used in the analysis of seepage patterns. The pattern and quantity of seepage into sump 188 N is almost identical to sump 187 S. This similarity is shown in Figure 4.3.

There are three sumps associated with tank WM-189: two hot sumps (189 S and 189 N) and one cold sump (189 C). The hot sumps are located next to the tank to receive any leakage from the tank. The cold sump is outside a dike in the floor of the vault to collect seepage into the vault along the walls. The water level inside the dike in vault 713/189 is above the level of the sumps. Both sumps show identical water level patterns throughout the study period. Sump 189 S is the sump used to jet water from the vault to the PEW evaporator, and so sump 189 S data were used in the analysis. The seepage into sump 189 S seems to be more or less continuous with only slight increases in rate during the spring of the year (Figure 4.5).

The cold sump in vault 713/189 showed very peculiar behavior, which did not lead to a very meaningful analysis of patterns. There was considerable seepage into sump 189 C from January 1989 through February 1990, with a brief reduction between August 1989 and December 1989 (Figure 4.5). Monthly seepage totals ranged from a low of 0 in. in November 1989 to a maximum of 182 in. in March 1989. Typical monthly seepage totals were in the range of 51 to 81 in. per month.

During the first 6 months of 1989, the water level in sump 189 C rises rapidly and is abruptly cut off by jetting with no indication that a maximum level of any kind is being reached. After that, however, there seems to be a maximum water level where the plots level off at about 50 in. of water in the sump. This can be seen in July, August, and November 1989, January and February of 1990, and again in February of 1991 (Appendix A). The water level on the last day of June 1989 is 52 in., and on the first day of July 1989 is 25 in. There seems to be a shift in the reference point for water level measurements. There are long periods of gradual water-level decline in sump 189 C while the hot sumps show significant influxes of water. When water does enter the sump, water-level rises of 3 to 6 in. are more common as compared to water-level rises of 60 in. in 1989. Then, in July 1992, the cold sump is allowed to fill and the water level rise above the top of the sump. Due to the Land Disposal Restrictions imposed in the spring of 1992 the sumps were allowed to rise and were only jetted to prevent overtopping. Water levels are above the top of the sump between July 1992 and May 1993. In May 1993, the water level is again drawn down into the sump.

To perform a meaningful statistical analysis of patterns, there must be a continuity in the data set. For sump 189 C, there are a number of changes which make data collected over different time periods non-comparable. Data from January 1989 to February 1990 indicate very much greater seepage rates than after February 1990. In addition, during this same period, there seems to be a change in the vertical position of the measuring point. Because of these significant changes in the data, analysis of data from sump 189 C did not provide very meaningful results.

The final vault, vault 713/190, contains three sumps also: two hot sumps (190 N and 190 S) and one cold sump (190 C) separated from the waste tank by a curb. Seepage into the cold sump, 190 C, is continuous throughout the study period with slight increases in the rate in the spring (Figure 4.5). The water level remains within the sump until February 1993, when the water level rises above the sump and floods the vault. Seepage data for this period were estimated based on a ratio of the area of the sump to the area of the vault outside the curb. This estimation had to be done so that seepage data for the period of February 1993 through May 1993 were comparable to the rest of the data for 190 C. The total amount of seepage into sump 190 C is the greatest of all of the sumps.

The two hot sumps in vault 713/190 showed very different patterns. In fact, the water level in sump 190 N would frequently be decreasing while the water level in sump 190 S was increasing. The level of water in sump 190 N was below the top of the sump for most of the period. There is an abrupt shift in sump level between June and July 1992. After this shift, the water levels in sumps 190 N and 190 S appear to be connected. The water level in sump 190 S appears to be above the top of the sump. Why there is no connection to sump 190 N, however is not clear. Cumulative seepage into sump 190 S is shown in Figure 4.4. Seepage into sump 190 S is almost continuous, with only a few dry months, usually in the middle of winter. In addition to the continuous seepage, there are significant steps in the seepage plot in the spring, indicating a significant response to seasonal precipitation.

4.2.3 Discussion

All of the cumulative seepage curves showed some response in the spring to recharge. The seepage data are summarized in two figures, Figure 4.6 and Figure 4.7. Both figures illustrate trends in seepage with time and allow easy comparison between sumps. Data used in these plots is normalized by total seepageⁱ over the 54 months so that sumps with large amounts of seepage do not obscure the detail for sumps with small amounts of seepage. If seepage was evenly distributed over the entire study period, 2% of the seepage would occur each month. Figure 4.6 shows the data as a surface map, and Figure 4.7 shows the same data as a contour map. The most prevalent trend in the data is that almost all sumps show a sharp increase in seepage between January and April, during spring snowmelt and recharge. Only sumps 180 S and 181 S do not show the effects of spring recharge. In both figures, the effects of continuous seepage during the summer and fall can be seen for sumps 189 S, 190 C, and 190 S.

4.3 Weather Data

This section discusses the weather data that were used to estimate recharge to the tank farm. Weather data are collected at the Central Facilities Area (CFA) by the National Oceanic and Atmospheric Administration (NOAA). Parameters measured at CFA include precipitation, snowfall, and snowpack depth. This complete suite of parameters is not available elsewhere on the INEL, and so the CFA data are used in the analysis. CFA is located only three miles from ICPP, and at basically the same elevation. There are no topographic features, such as ridges or hills, that would affect precipitation between the two facilities. Therefore, the CFA data are considered to be representative of conditions at ICPP.

4.3.1 Basic Precipitation Records

Daily measurements of precipitation, snowpack, and snowfall were obtained from NOAA on magnetic disk in ASCII format. These data were uploaded into an EXCEL spreadsheet. Monthly totals for precipitation and snowfall, and the snowpack on the ground at the end of the month were determined for the months from January 1988 through June 1993. In general, this period was one of below normal precipitation. Table 4.2 shows the monthly precipitation amounts for each year compared to the long term monthly averages. The spring of 1993 was the only extended period of above normal precipitation.

i. Seepage for each month is divided by the total amount of seepage for the study period. The resulting normalized seepage is the percent of the total amount of seepage that occurs in each month.

Sharp peaks in the spring of each year indicate an increase in seepage in response to snow melt.

FIGURE 4.6
SEEPAGE INTO VAULT SUMPS BETWEEN
JANUARY 1989 AND JUNE 1993
WINCO/PERCHED WATER SUPPORT/AD

4.3.2 Estimation of Water Available for Recharge from Weather Records

Precipitation falling during the winter may build up on the ground as snow pack rather than infiltrate into the ground. Therefore, the water available for recharge (called recharge in the rest of this report) was estimated from the weather data. For each month, three numbers are available, the total precipitation in inches, the inches of snowfall, and the snowpack on the ground at the end of the month (Table 4.3). To estimate recharge from precipitation, the first step was to determine if there was an increase in snowpack on the ground. If there was no increase, then the amount of precipitation was considered to all be available for recharge. If there was an increase in the snowpack, then the increase in the water content of the snowpack was calculated from:

$$\Delta H_2O = \left(\frac{Pack_m - Pack_{m-1}}{Snowfall} \right) \times Precip$$

where:

ΔH_2O	=	Increase in water content of snowpack (in.)
$Pack_m$	=	Snowpack depth at end of current month (in.)
$Pack_{m-1}$	=	Snowpack depth at end of previous month (in.)
Snowfall	=	Total monthly snowfall (in.)
Precip	=	Total monthly precipitation (in.)

For example, the snowpack at the end of January 1990 was 5.0 in. ($Pack_m$), the snowpack at the end of December 1989 was 3.0 in. ($Pack_{m-1}$), the snowfall for the month of January 1990 was 6.0 in., and to total precipitation for January 1990 was 1.05 in. The water added to the snowpack was calculated to be 0.35 in. $[(5-3)/6 \times 1.05]$ with the remaining 0.70 in. $[1.05 - 0.35]$ of water being available for recharge. The water added to the snowpack was accumulated as long as the snowpack was growing so that the total amount of water in the snowpack was known. When the snowpack decreased from one month to the next, the percent decrease in the depth of snowpack was used to calculate the percentage of the accumulated water that was released. This provided an estimate of when water was available for recharge rather than when precipitation occurred. For example, the snowpack reached a depth of 30 in. during the winter of 1993 and contained an estimated 2.57 in. of water. This moved a significant volume of recharge from the months of December 1992, January 1993, and February 1993 into March. This method does not take into account compaction of the snowpack without loss of water and therefore is only an estimate of the water available for recharge. No data on the actual water content of snow are available, and therefore, this is the best estimate of recharge that can be made with existing data. Recharge calculated for input to the regression model is shown in Table 4.3.

Table 4.2 Comparison of monthly precipitation during the study period to long-term averages.

Month	Avg 1950- 1988 (in.)	1988 (in.)	1989 (in.)	1990 (in.)	1991 (in.)	1992 (in.)	1993 (in.)
Jan	0.69	0.50	0.31	1.05	0.05	0.01	1.15
Feb	0.64	0.00	0.38	0.15	0.00	0.45	1.44
Mar	0.60	0.08	0.62	0.19	1.18	0.28	0.57
Apr	0.73	1.28	0.31	0.97	0.51	0.06	1.20
May	1.20	0.56	0.75	1.28	2.03	0.31	1.99
Jun	1.18	0.13	1.21	0.86	1.15	1.53	2.73
Jul	0.53	0.04	0.32	0.59	0.53	0.25	
Aug	0.57	0.04	0.41	0.68	0.78	0.07	
Sep	0.63	0.23	1.86	0.05	1.08	0.58	
Oct	0.52	0.01	0.29	0.25	0.51	0.33	
Nov	0.68	1.74	0.45	0.18	0.73	0.47	
Dec	0.75	0.80	0.04	0.23	0.00	1.16	
Total	8.72	5.48	6.95	6.48	8.55	5.50	9.08*

a First 6 months

Table 4.3 Meteorologic data used to determine recharge and calculated recharge to the tank farm

	Precip (in.)	Snow (in.)	Last snow pack (in.)	H2O added to pack	Fraction melted	Total H2O in pack	Water released (in.)	Re- charge (in.)
Jan-88	0.50	5.00	1.00	0.00	-0.67	0.27	0.18	0.68
Feb-88	0.00	0.00	0.00	0.00	-1.00	0.09	0.09	0.09
Mar-88	0.08	0.50	0.00	0.00	0.00	0.00	0.00	0.08
Apr-88	1.28	0.00	0.00	0.00	0.00	0.00	0.00	1.28
May-88	0.56	0.00	0.00	0.00	0.00	0.00	0.00	0.56
Jun-88	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.13
Jul-88	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.04
Aug-88	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.04
Sep-88	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.23
Oct-88	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Nov-88	1.74	10.80	4.00	0.64	0.00	0.64	0.00	1.10
Dec-88	0.80	8.40	10.00	0.57	0.00	1.22	0.00	0.23
Jan-89	0.31	3.90	12.00	0.16	0.00	1.37	0.00	0.15
Feb-89	0.38	5.20	14.00	0.15	0.00	1.52	0.00	0.23
Mar-89	0.62	2.00	0.00	0.00	-1.00	1.52	1.52	2.14
Apr-89	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.31
May-89	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.75
Jun-89	1.21	0.00	0.00	0.00	0.00	0.00	0.00	1.21
Jul-89	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.32
Aug-89	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.41
Sep-89	1.86	0.00	0.00	0.00	0.00	0.00	0.00	1.86
Oct-89	0.29	0.20	0.00	0.00	0.00	0.00	0.00	0.29
Nov-89	0.45	4.50	4.00	0.40	0.00	0.40	0.00	0.05
Dec-89	0.04	0.20	3.00	0.00	-0.25	0.40	0.10	0.14
Jan-90	1.05	6.00	5.00	0.35	0.00	0.65	0.00	0.70
Feb-90	0.15	3.00	0.00	0.00	-1.00	0.65	0.65	0.80
Mar-90	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.19
Apr-90	0.97	0.00	0.00	0.00	0.00	0.00	0.00	0.97
May-90	1.28	0.00	0.00	0.00	0.00	0.00	0.00	1.28
Jun-90	0.86	0.00	0.00	0.00	0.00	0.00	0.00	0.86
Jul-90	0.59	0.00	0.00	0.00	0.00	0.00	0.00	0.59
Aug-90	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.68
Sep-90	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Oct-90	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.25
Nov-90	0.18	1.30	1.00	0.14	0.00	0.14	0.00	0.04
Dec-90	0.23	4.20	4.00	0.16	0.00	0.30	0.00	0.07

Table 4.3 Continued

	Precip (in.)	Snow (in.)	Last snow pack (in.)	H2O added to pack	Fraction melted	Total H2O in pack	Water released (in.)	Re- charge (in.)
Jan-91	0.05	0.50	2.00	0.00	-0.50	0.30	0.15	0.20
Feb-91	0.00	0.00	0.00	0.00	-1.00	0.15	0.15	0.15
Mar-91	1.18	0.80	0.00	0.00	0.00	0.00	0.00	1.18
Apr-91	0.51	1.00	0.00	0.00	0.00	0.00	0.00	0.51
May-91	2.03	0.00	0.00	0.00	0.00	0.00	0.00	2.03
Jun-91	1.15	0.00	0.00	0.00	0.00	0.00	0.00	1.15
Jul-91	0.53	0.00	0.00	0.00	0.00	0.00	0.00	0.53
Aug-91	0.78	0.00	0.00	0.00	0.00	0.00	0.00	0.78
Sep-91	1.08	0.00	0.00	0.00	0.00	0.00	0.00	1.08
Oct-91	0.51	2.40	1.00	0.21	0.00	0.21	0.00	0.30
Nov-91	0.73	4.60	2.00	0.16	0.00	0.37	0.00	0.57
Dec-91	0.00	0.00	0.00	0.00	-1.00	0.37	0.37	0.37
Jan-92	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Feb-92	0.45	1.30	0.00	0.00	0.00	0.00	0.00	0.45
Mar-92	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.28
Apr-92	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.06
May-92	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.31
Jun-92	1.53	0.00	0.00	0.00	0.00	0.00	0.00	1.53
Jul-92	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.25
Aug-92	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.07
Sep-92	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.58
Oct-92	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.33
Nov-92	0.47	5.50	3.00	0.26	0.00	0.26	0.00	0.21
Dec-92	1.16	16.40	18.00	1.06	0.00	1.32	0.00	0.10
Jan-93	1.15	10.10	22.00	0.46	0.00	1.77	0.00	0.69
Feb-93	1.44	14.50	30.00	0.79	0.00	2.57	0.00	0.65
Mar-93	0.57	0.00	0.00	0.00	-1.00	2.57	2.57	3.14
Apr-93	1.20	3.50	0.00	0.00	0.00	0.00	0.00	1.20
May-93	1.99	0.00	0.00	0.00	0.00	0.00	0.00	1.99
Jun-93	2.73	0.00	0.00	0.00	0.00	0.00	0.00	2.73

4.3.3 Evaporation

Water in the soil will be lost to the atmosphere by evaporation during the summer. Measurements of the amount of evaporation from soils at ICPP have not been made. Evaporation from free standing water in pans has been estimated by NOAA for the INEL. The total annual pan evaporation is estimated to be 43 in. (Clawson et al. 1989). About 29 in. of this evaporation occurs between the months of May and October. The potential evaporation therefore, exceeds the input of water by precipitation during the summer. There are no measurements at ICPP that would permit calculation of actual evaporation from soils during the study period. Therefore, no attempt was made to calculate net infiltration from the recharge data and evaporation data. However, the high evaporation rates during the summer months were factored into the regression model by including a seasonal term in the equation. Net recharge to the tank farm is represented by the sum of two factors: total water input, or recharge; and evaporation losses, modeled by a sine function.

4.4 Regression Analysis

The model presented in Section 4.1 was fit to the sump data shown in Table 4.1. Table 4.4 summarizes the results of the regression analyses. Complete printouts of the regression analyses are included as Appendix B.

Not all sumps were included in the analysis. Table 2.4 indicates that the average volume of water jetted from the tank farm per month was 2,473 gal. The sumps analyzed account for 2,281 gal per month, or 92% of the total volume of water. Therefore, the analysis and conclusions are very representative of tank farm seepage, and any conclusions should not be affected by not including the additional sumps.

There are a number of general observations that can be drawn from the analysis. All of the sumps showed a significant response to recharge as indicated by the C_1 coefficient (Table 4.4). All sumps also showed a significant seasonal response as indicated by the C_2 coefficient. All of the sumps in vault 713 showed significant constants (C_0). For none of the other vaults was the constant term, C_0 , significantly greater than zero. The percent of the total variation in the seepage data explained by the regression model ranges from 15% for sump 189 C to 79% for sump 188 N. Even when the percent of the total variation in the seepage data explained by the regression analysis was small, such as for sump 189 C, the coefficients of the regression model were statistically significant. Therefore, for some sumps the random sources of variation dominate the total variation, but infiltration of precipitation is still a significant source of seepage.

Figures 4.7 through 4.16 show a comparison between the actual cumulative seepage and the predicted cumulative seepage. The initial and end points of the plots are constrained to be equal. Deviations in between reflect times when the model did not accurately match the data. Additional plots showing month by month comparisons of predicted and observed seepage are shown in Appendix B.

For sump 183 N, the model matches spring recharge effects for 1991 and 1993 very well (Figure 4.7). Spring recharge is underestimated for 1989 and overestimated for 1990 and 1992. The large response to recharge in the spring of 1989 is responsible for the relatively low percent variation explained for sump 183 N, only 29%. However, looking at the plot, it seems apparent that spring recharge is responsible for essentially all of the seepage into vault WM-783.

Table 4.4 Summary of regression analysis results.

Sump	Percent Variation Explained	Constant C_0	Probability that $C_0 = 0$	Recharge C_1	Probability that $C_1 = 0$	Amplitude C_2 (Offset, days)	Probability that $C_2 = 0$
180 S	Not run						
181 S	Not run						
182 S	Not run						
183 N	29%	0.3088	0.175	0.4257	<0.001	0.6958 (18.3)	0.010
184 N	54%	0.0074	0.697	0.0637	<0.001	0.0716 (26.9)	0.003
185 S	76%	0.0202	0.786	0.4428	<0.001	0.1892 (27.2)	0.027
186 S	49%	0.1298	0.109	0.2403	<0.001	0.2272 (-6.2)	0.016
187 S	78%	0.1821	0.080	0.6285	<0.001	0.4712 (23.8)	<0.001
188 N	79%	0.2042	0.028	0.5667	<0.001	0.4187 (24.1)	<0.001
189 C	15%	15.2174	0.010	7.5629	0.012	11.0837 (-8.1)	0.070
189 S	61%	4.2400	<0.001	2.6198	<0.001	1.8416 (2.0)	0.018
190 C	47%	18.4490	<0.001	8.1856	<0.001	8.7065 (-67.4)	0.013
190 S	40%	0.9691	<0.001	0.3342	0.002	1.0340 (-43.0)	<0.001

a. Coefficients with a significance less than 90% (probability greater than 0.10), shaded, are considered to equal zero.

Actual seepage into vault WM-784 occurs only during the spring of the year (Figure 4.8). The model very well matches the seepage in 1989, 1991, 1992 and 1993. There was no seepage in the spring of 1990. The seepage data support a conclusion that the only source of seepage into vault WM-784 is infiltration of precipitation.

The model fits the seepage data for sump 185 S very well (Figure 4.9) with a percent variation explained of 76%. Even though this sump shows a more gradual influx of seepage, the constant term in the equation is zero. Therefore, there is not a source of constant seepage into vault WM-785, and essentially all of the seepage can be attributed to infiltration of precipitation.

Sump 186 S shows a very stair-step pattern of seepage, and very irregular response to recharge (Figure 4.10). The model fits spring recharge in 1989 and 1993 very well. However, there is no seepage during the spring of 1990, which is not accounted for by the model. The constant term in the equation is not considered significant. The actual data do not support a constant seepage into the vault with the very flat periods during the summer. Therefore, the seepage pattern for vault WM-786 most closely follows that of infiltration of precipitation.

Sump 187 S is the first sump to show a constant term for seepage that is significantly different than zero. All of the sumps in vault WM-713 showed a significant constant term for the model. The model fits the seepage data for 187 S very well (Figure 4.11) with 78% of the variation in the data explained by the model. There is a constant seepage into the vault of about 0.2 in. per month. There is also a significant contribution from recharge, with increases in seepage rate each spring.

Sump 188 N is very close to sump 187 S, and shows a similar pattern and quantity of seepage. The model also fits the seepage data from 188 N very well with 79% of the variation in the seepage data explained by the model.

Sump 189 C did not show consistent patterns throughout the study period, and therefore the model did not fit the data very well with only 15% of the variation in the data explained. Figure 4.13 shows that sump levels rose very quickly during 1989 and 1990, then leveled off with only slight response to infiltration after the spring of 1990. Because of this change in the middle of the study period, the model did not match the data. After the summer of 1990, however, the only time seepage entered the sump was during the spring. The response coefficient for recharge, C_1 , is significant indicating that recharge is a significant source of recharge.

Seepage into sump 189 S showed a significant constant term as well as a significant recharge response term. The model fit the data fairly well (Figure 4.14) with 61% of the variation in the data explained by the model.

Both sumps associated with tank WM-190 showed significant constant terms and recharge terms. The models fit moderately well with 47% of the variation explained for sump 190 C and 40% of the variation explained for sump 190 S. The lower fit of the model for sump 190 S is due to a very large response to recharge during the spring of 1991. The model fit the other periods reasonably well.

One aspect of seepage into sumps is that the offset for the seasonal cycle varies from about -67 days to about +25 days. One group of sumps has a seasonal cycle with an offset of about +25 days. This gives a maximum in March and a minimum in September, consistent with recharge and evaporation. Sumps 189 S and 189 C have offsets near 0 days, and 190 S and 190 C have offsets of -43 and -67 days respectively. This difference suggests an additional process with seasonal

components modifying the seasonal cycle. The large negative offset for vault 713/190 changes the maximum in the seasonal cycle from March to July.

One way to achieve this pattern is to combine two seasonal cycles, one with a maximum in March and April (net recharge) and a second seasonal cycle with a maximum in August and September (lawn watering). The sum is a seasonal cycle with a different amplitude and a maximum intermediate between the two. This effect is illustrated in Figure 4.17. Evaporation would have a seasonal cycle, with little or no evaporation in winter, and maximum evaporation during the late summer and fall. For most vaults there is no seepage into the vault during the summer, and so the sum of the recharge term and the evaporation cycle (i.e. net recharge) must be zero in late summer. Therefore, the evaporation cycle has to be negative by an amount proportional to the square of the recharge in late summer. The evaporation cycle in Figure 4.17, therefore is negative in the late summer and early fall. The average of the cycle, and therefore the constant term in the regression equation, is therefore, zero.

Lawn watering takes place during the summer with a peak in August. No water is applied during the winter so the minimum in the lawn water cycle is zero. The average, or constant term, is therefore non-zero.

Summing the evaporation cycle and the lawn watering cycle (Figure 4.17) shows a cycle with a non-zero average and a maximum that is intermediate between the evaporation cycle and the lawn watering cycle. One possible explanation for the difference in the cycle offsets and non-zero constants for sumps 190 S and 190 C is that water used for lawn watering is entering these sumps. Sumps in vault 713/189 could also show some effects of lawn watering, but at a lower contribution from the lawn. The change in offset for sump 186 S is not likely due to lawn watering, and no ready explanation is offered.

4.5 Discussion

Some generalizations about seepage into tank farm vaults can be drawn from the statistical analysis of patterns. These generalizations refer only to vaults WM-783 through WM-786 and WM-713. Vaults WM-780 through WM-782 were not analyzed because of the very sparse data for those vaults.

- All vaults analyzed had significant increases in seepage in response to recharge. Sumps in vaults WM-783 through WM-786 show patterns that suggest essentially all of the seepage is from precipitation.
- Only sumps in vault WM-713 show evidence of a source of constant seepage.
- Sumps at the far eastern edge of the tank farm show changes in seasonal patterns consistent with a contribution from lawn watering.

FIGURE 4.7
COMPARISON OF MEASURED AND
PREDICTED SEEPAGE FOR SUMP 183N
 WINGOPERCHED WATER SUPPORT/D

Golder Associates

184 N

FIGURE 4.8
COMPARISON OF MEASURED AND
PREDICTED SEEPAGE FOR SUMP 184N
 WINCOPERCHED WATER SUPPORT/AD

FIGURE 4.9
**COMPARISON OF MEASURED AND
 PREDICTED SEEPAGE FOR SUMP 185S**
 WINCO PERCHED WATER SUPPORT/AD

186 S

FIGURE 4.10
COMPARISON OF MEASURED AND
PREDICTED SEEPAGE FOR SUMP 186S
WINCOPPERCHED WATER SUPPORT/ID

PROJECT NO. 803 1150 DRAWING NO. 47105 DATE 10/5/93 DRAWN BY TB

Golder Associates

187 S

FIGURE 4.11
COMPARISON OF MEASURED AND
PREDICTED SEEPAGE FOR SUMP 187S
WINCO/PERCHED WATER SUPPORT/ID

188 N

FIGURE 4.12
COMPARISON OF MEASURED AND
PREDICTED SEEPAGE FOR SUMP 188N
 WINCOPPERED WATER SUPPORT MD

Golder Associates

PROJECT NO. 533 1150 DRAWING NO. 47108 DATE 10/5/93 DRAWN BY TB

FIGURE 4.14
COMPARISON OF MEASURED AND
PREDICTED SEEPAGE FOR SUMP 189S
WINCOPERCHED WATER SUPPORT/ID

FIGURE 4.15
COMPARISON OF MEASURED AND
PREDICTED SEEPAGE FOR SUMP 190C
 WINCO/PERCHED WATER SUPPORT/D

190 S

FIGURE 4.16
COMPARISON OF MEASURED AND
PREDICTED SEEPAGE FOR SUMP 190S
 WINCO/PERCHED WATER SUPPORT/ID

FIGURE 4.17
 ILLUSTRATION HOW THE SUM OF TWO SEASONAL
 CYCLES CAN PRODUCE A THIRD SEASONAL CYCLE
 OF DIFFERENT AMPLITUDE AND PHASE SHIFT
 WINCO/PERCHED WATER SUPPORT/ID

5. CHEMISTRY OF WATER IN SUMPS AND SOURCES

This section discusses results of chemical and radiological analysis of water from cold sumps associated with tanks 189 and 190. Samples were collected from sumps 189 C and 190 C and submitted for analysis of metals, major ions, and radionuclides. Water samples were also collected from potable water in building CPP-699 and from the raw water line feeding the lawn sprinkler in back of CPP-699. These latter two samples were to provide information on potential sources of sump seepage, and were analyzed for the same list of parameters. Data were collected on water chemistry to attempt to identify links between sump water and sources based on chemical similarities.

5.1 Sampling and Analysis

5.1.1 Sample Locations

Samples were collected from sumps 189 C and 190 C for analysis of chemical and radionuclide parameters. These two sumps were identified for sampling because:

- They are at the eastern end of the tank farm where most of the seepage is taking place.
- They are in vaults that show seepage throughout the year, which suggests a source other than infiltration of precipitation.
- The sumps can be sampled through access pipes.

Sumps in other vaults were given a much lower priority and were not sampled. Reasons for this include:

- The volume of seepage into the other vaults is much smaller than the volume of seepage into vault 713.
- The pattern of seepage into the other vaults is much more clearly related to spring infiltration than vault 713, which shows infiltration throughout the year.
- To sample the other sumps would require a crane to remove concrete hatch covers as there are no access pipes to any hot sumps.
- Because of contamination of vaults from past waste spills, unequivocal conclusions could be difficult to draw from the data.

Samples of the potable water in building CPP-699 and raw water from the sprinkler system were also collected and analyzed for the same parameters as the sumps. This provides data comparable to that collected from the sumps.

5.1.2 Discussion of Detection Limits

One sample was collected from sump 189 C in December 1992. Samples of the cold sumps 189 C and 190 C were also collected July 15th and 16th, 1993. The sampling procedure requires lowering a small vial 50-ft down a small-diameter access pipe using a nylon cord. A total of 270 mL of sample

was collected from each sump. More sample was not collected because collection is difficult due to a screen over the sump. Analysis of water samples for the complete suite of requested parameters following EPA procedures would require approximately 5,000 mL of water. If EPA sample preparation protocols are relaxed, and water is used to run multiple analyses where possible, the complete suite of analyses would require about 1700 mL of water. Because only 270 mL of water was available from each sump, sample preparation procedures were significantly altered so that enough sample was available for analysis. As a result, the detection limits for these samples are very high. Although sufficient of water was available from the raw and potable water sources, the same sample preparation and analytical procedures were used to provide comparable data.

5.2 Analytical Results

Results of chemical and radionuclide analyses on water samples are shown in Table 5.1. Uranium and chromium were the only metals detected above method detection limits shown in the table. Chromium was detected at 204 $\mu\text{g/L}$ in the sample collected from sump 189 C in December. Radionuclide detection limits were also very high, and Cs-137 is the only nuclide detected consistently in the sump-water samples. No gamma-emitting radionuclides were detected in the raw or potable water.

Major chemical species were analyzed on the water samples. Both raw water and potable water are pumped from the Snake River Plain Aquifer. The water comes from two different wells, but the wells are located close together at the north end of ICPP. The water chemistry of the two samples is very similar reflecting the common origin. There are no distinct differences that would permit differentiating raw water from potable water.

The two water samples collected from sumps 189 C and 190 C in July also show similar chemical compositions. The compositions are not identical, but close enough to suggest a common origin for the water in both cold sumps.

There is very little information to compare between the December and July samples from sump 189 C. There is one very large difference, in that the pH of the December sample was 6.74 and the pH of the July sample was 8.57. Most soils at the INEL are alkaline (Martin et al. 1990), and water with a pH as low as 6.74 would not normally be expected. Precipitation in equilibrium with atmospheric carbon dioxide has a pH of 5.7. Addition of acid gasses to the atmosphere such as NO_2 and SO_2 , could lower this pH some. However, reactions in the soil with soil minerals, particularly calcite, would rapidly raise the pH.

The sample collected in December was collected at a time of year when most of the water entering the vaults would be from precipitation. Watering of the lawn in back of CPP-699 would have ceased in October. There was some net recharge calculated for November and December 1992 as shown in Table 4.3. In December, soil would be very cold and so chemical and biological reactions would be slow. It is possible that the water sample collected in December represents snow melt that seeped into the vault through gaps in the membrane at riser pipes or valve boxes. This water would have passed through very little soil under cold soil conditions. As a result, little chemical reaction may have occurred to raise the pH. There is no additional information such as specific conductance or total alkalinity to provide information to evaluate this pH measurement. Because of the lack of supporting analytical information, the explanation for the low pH in December cannot be determined.

Table 5.1 Analytical results from samples collected from cold sumps and potential water sources for the tank farm

	189 C	189 C	190 C	Potable	Raw	MCL (a)	Units
Date Collected	12/15/92	7/15/93	7/15/93	8/18/93	8/18/93		
Metals							
Aluminum		< 218,000	< 175,500	< 45,260	< 45,260	200	ug/L
Arsenic	< 141	< 1,298	< 1,298	< 1,120	< 1,120	50	ug/L
Barium	< 178	< 366	< 366	< 466	< 466	2,000	ug/L
Boron		< 40,200	< 40,200	< 10,370	< 10,370		ug/L
Cadmium	< 244	< 878	< 878	< 898	< 898	5	ug/L
Chromium	204	< 736	< 736	< 769	< 769	100	ug/L
Iron		< 12,230	< 12,230	< 3,153	< 3,153	300	ug/L
Lead	< 180	< 787	< 787	< 866	< 866	15	ug/L
Manganese		< 50,750	< 50,750	< 13,000	< 13,000	50	ug/L
Mercury	< 17	< 11	< 6.3	< 9	< 9	2	ug/L
Molybdenum		< 50,750	< 50,750	< 13,000	< 13,000		ug/L
Nickel	< 227	< 752	< 752	< 786	< 786	100	ug/L
Selenium	< 224	< 654	< 654	< 508	< 508	50	ug/L
Silver	< 205	< 435	< 435	< 914	< 914		ug/L
Uranium		60	30	60	70		ug/L
Zirconium		< 141,400	< 141,400	< 36,460	< 36,460		ug/L
Physical Properties							
pH	6.74	8.57	8.72	8.35	8.30	6.5 - 8.5	
Conductance		391	343	9.19	9.35		uS/cm
Total Org C		2.6	< 5	4.6	< 1		mg/L
Total Inorg C		47.65	43.35	26.8	34.55		mg/L
Cations							
Calcium		< 100	< 100	51.0	51.3		mg/L
Magnesium		21.2	18.8	16.4	15.7		mg/L
Sodium		52.0	49.0	8.3	9.1	20	mg/L
Potassium		29.0	34.0	2.8	2.6		mg/L
Sum epn		—	—	4.33	4.32		epn
Anions							
Bicarbonate		242	220	136	176		mg/L
Chloride		16.4	< 29.9	< 18.7	< 18.7	250	mg/L
Sulfate		24.0	20.7	32.0	23.5	250	mg/L
Nitrate		29.0	39.4	5.0	5.3	44	mg/L
Phosphate		< 4.5	< 4.5	< 1	< 1		mg/L
Sum epn		5.40	—	—	—		epn

Table 5.1 Continued

	189 C	189 C	190 C	Potable	Raw	DCG (b)	Units
Date Collected	12/15/92	7/15/93	7/15/93	8/18/93	8/18/93		
Radionuclides							
Gross alpha	< 8,800	< 15,100	< 15,100	< 15,100	< 15,100	15	pCi/L
Gross beta	< 360,000	< 135,000	< 81,000	< 183,000	< 183,000	50	pCi/L
Co-60	920			ND	ND	10,000	pCi/L
Cs-137	3,700	124,000	39,500	ND	ND	300	pCi/L
Sr-90	< 22,800	79,460	< 12,000	< 1,400	< 2,500	100	pCi/L
Tritium		< 4.3E+06	< 4.3E+06	< 4,250	< 4,250	2.0E+06	pCi/L
I-129	< 6,250	< 110,000	< 110,000	< 3,700	< 3,700	500	pCi/L
Am-241		< 876	< 2,630	< 657	< 657	30	pCi/L
Pu-238		< 1,240	< 3,700	< 930	< 930	40	pCi/L
Pu-239		< 1,240	< 3,700	< 930	< 930	30	pCi/L
U-234		4.00E-05	11,200	3,740	4,370	500	pCi/L
U-235		76	28	61	73	600	pCi/L
U-236		270	135	233	181	500	pCi/L
U-238		6.8	4.4	9.3	11	600	pCi/L

(a) MCL - Maximum contaminant limit. Numbers in italics are secondary limits.

(b) DCG - Derived concentration guide from DOE Order 5400.5.

5.3 Analysis of Ion Ratios

There are no complete analyses for major ionic species from the sumps or potential sources. Therefore, many standard techniques to analyze similarities or associations among water samples, such as piper diagrams, cannot be used. However, analysis of ion ratios can provide quite a bit of information about these samples.

One test that can be performed is to evaluate if mixing of HLLW and other water sources can explain the chemistry of water in the sumps. Two possible sources are identified: precipitation and raw water. Precipitation is assumed to have no dissolved chemicals for this calculation. Precipitation does have small amounts of dissolved chemicals, and may pick up additional chemicals passing through the soil. However, compared to HLLW, the assumption of no dissolved chemicals is reasonable, and will not affect the calculation significantly. The second source for which the calculation is performed is raw water. Raw water is used because it is the water used on the lawn in back of CPP-699. There is very little difference between raw water and potable water and the conclusions of the calculation would apply equally well to either water. Both sumps have very similar water chemistry, and so the two sumps are averaged for this calculation. Table 5.2 shows the concentrations of ions used in the calculation.

For a mixture of two waters, the resulting chemical composition can be calculated from:

$$x C_w + (1-x) C_m = C_s$$

where:

x	=	Mixing fraction
C_w	=	Concentration of HLLW
C_m	=	Concentration of second source
C_s	=	Concentration in sump.

For the situation of mixing with precipitation where C_m is zero, the mixing equation simplifies to:

$$x = \frac{C_s}{C_w}$$

For mixing with raw water with non-zero concentrations, the mixing equation solved for the mixing fraction is:

$$x = \frac{(C_s - C_m)}{(C_w - C_m)}$$

Performing these calculations with the data in table 5.2, gives the mixing fractions shown in Table 5.3.

The first thing that is apparent about the mixing fractions is that they are very small. It would take only a few tenths of one percent of HLLW to produce the concentrations observed in the sumps. However, there is a wide range in the ratios for the different chemical species for each possible source. If sump water was the result of simple mixing, all constituents would have a similar mixing fraction. Because of the wide range in mixing fractions, it is not likely that the major ion chemistry in the sump water is controlled by mixing of HLLW with another source.

Table 5.2 Chemical composition of potential sources of water in sumps. Concentrations in mg/L.

Constituent	HLLW ^a	Precipitation	Raw Water	Average Cold Sump	Ratio of Raw/Sump
NO ₃ ⁻	294,500	0	5.3	34	0.16
Cl ⁻	1,064	0	< 18.7	16.4	≈ 1
SO ₄ ⁻²	4,800	0	23.5	24	0.98
Na ⁺	46,000	0	9.1	50	0.18
K ⁺	7,800	0	2.6	32	0.08

a. Based on sodium-bearing waste in Table 2.1.

Table 5.3 Mixing fractions of HLLW with precipitation and raw water calculated for selected constituents in sump water.

Constituent	Fraction HLLW mixed with precipitation	Fraction HLLW mixed with raw water
NO ₃ ⁻	1.15E-04	9.75E-05
Cl ⁻	1.54E-02	—
SO ₄ ⁻²	5.00E-03	1.05E-04
Na ⁺	1.09E-03	8.89E-04
K ⁺	4.10E-03	3.77E-03

Nitrate is the dominant ion listed in Table 5.2. To achieve the level of nitrate measured in the sump water by mixing another source with HLLW takes only a very small amount of HLLW. The other ions listed in Table 5.2 require much greater mixing fractions than nitrate. The sodium-bearing waste is the highest in the alkali metals (sodium and potassium). Therefore, the mixing ratios for nitrate and sodium for sodium-bearing waste will be more similar than for the other waste streams. Therefore, none of the three types of HLLW listed in Table 2.1 could produce the observed sump-water chemistry by mixing.

Looking at the last column in Table 5.2 indicates that the concentrations of chloride and sulfate in sumps 189 C and 190 C are very similar to their concentrations in raw water. Chloride and sulfate are relatively conservative species in water, and there are not a lot of sources or sinks for these ions in the soil. The similarity in concentrations suggests that raw water or potable water is the source of seepage into the sumps. Other elements in Table 5.2 show an increase in concentration between raw water and sump water. Changes in water chemistry due to mineral reactions and leaching are more likely than simple mixing.

Another source of water that can be evaluated with existing data is leaking of water from the tank cooling system. Water in the tank cooling system is maintained at 500 mg/L chromate (CrO_4^{2-})^j added as potassium dichromate. For every mole of chromate ion in the cooling water, there is also one mole of potassium. There is a relatively high potassium concentration in the sump water and a large increase over potable and raw water potassium concentrations. If the potassium in the sump water, 32 mg/L, was from leaking of the cooling system, there would be a chromium concentration (Cr) of 43 mg/L. Water analyses show that chromium concentrations are well below this level, and so leaking of cooling coils is not a likely source of water for sumps 189 C and 190 C.

5.4 Chemical Evolution Model

Complete analyses are not available for the water samples, and no information is available on the concentrations of calcium in the sump water or chloride in the raw/potable water. The concentrations of these ions can be estimated, however, by balancing the positive and negative charges in the water. A water must exist in a state of electrical neutrality. That is, the number of positive ions must equal the number of negative ions. Based on the incomplete analyses, the calcium and chloride concentrations needed to produce electrical neutrality can be estimated. This introduces a large uncertainty in the data because it is not known if other, unanalyzed, compounds are contributing to the charge balance, or if there are analytical errors in the data. Either of these factors could result in large errors in the estimated concentrations of calcium and chloride.

Figure 5.1 A and B show the changes in ion concentrations between raw water and sump water. The vertical line shows the change, with the tick mark indicating the concentration in the sump. This estimate indicates that the calcium concentration in the sump water is lower than in the raw water. Chloride and sulfate concentrations are very similar in both raw/potable and sump water, and the rest of the ions show an increase between raw/potable water and sump water. Figure 5.1 B and C illustrate the contribution to the total charge of the solution from each of the ions.

The following explanation of these changes is offered. Raw water is used to water the lawn in back of CPP-699. In the soil, the water dissolves carbon dioxide generated by plant root respiration resulting in the addition of carbonic acid to the water.

j. Chemical Plant Operating Procedure 4.3.5.6, "Tank Farm Cooling System in the Tank Farm".

Carbonic acid then dissolves calcite in the soil to increase the concentration of bicarbonate and calcium in the water.

The sump water is lower in calcium and higher in sodium than the raw water, however. Therefore, an additional reaction must occur where calcium in the water exchanges with sodium on exchange sites of clays in the soil. Clay minerals show a strong preference for divalent cations over monovalent cations (Stumm and Morgan 1970; Foth 1978) so this reaction is favored by thermodynamics.

The net reaction is to increase the concentrations of bicarbonate and sodium in the water with a corresponding decrease in calcium concentration.

Potassium and nitrate concentrations also increase in the water between the raw water and the sump. This is hypothesized to be from leaching of fertilizer used on the grass in back of CPP-699.

5.5 Discussion

Limited chemical analytical data were obtained from sumps in the tank farm. The only sumps sampled are the cold sumps associated with tanks 189 and 190. However, these are the tanks that have the most continuous seepage, and therefore, identifying this extra source of water is of the most interest. Mixing fractions calculated for different ionic species for the mixing of HLLW with other sources give very different mixing fractions. Therefore, simple mixing does not seem to be responsible for sump water chemistry. Conservative ions chloride and sulfate have very similar concentrations in raw water and in the sump water. This suggests a connection. A chemical evolution model is proposed that could explain the changes in water chemistry. Analyses are too incomplete to quantitatively evaluate this model.

B

A

D

C

FIGURE 5.1
COMPARISON OF THE COMPOSITION OF
RAW OR POTABLE WATER AND WATER IN
THE COLD SUMPS 189C AND 190C
 WINCOPPERED WATER SUPPORTAD

6. SOIL MOISTURE BALANCE AND INFILTRATION

This section describes investigations conducted to evaluate the movement of moisture in the vadose zone at the tank farm. The purpose of these investigations is to determine the quantity of water available for seepage into the tanks, the potential for precipitation recharging deep perched groundwater, and to evaluate the pathways water might take to enter the vaults. No additional data were collected for this part of the investigation. Analyses are based on a review of existing data and reports.

The purpose of this section is to discuss moisture movement for the tank farm. No investigations were conducted to gather data specific to the tank farm. Data from other locations on the INEL are reviewed and computer simulations run to evaluate possible moisture movement. Conclusions from this section address the quantity of moisture available for infiltration into the vaults and recharge of perched water. Also addressed is the lateral spreading of infiltration as it migrates downward through surficial sediments. The lateral spreading issue is addressed to evaluate the possibility for water from beyond the membrane to migrate laterally to the vault roofs.

6.1 Net Infiltration

The INEL is in a desert climate with low precipitation and high evaporation. The long-term average annual precipitation at CFA is 8.7 in. Estimated pan evaporation is on the order of 43 in. per year. Therefore, there is an overall net water deficit for the Site. Because of the cold winters, however, a snow pack usually develops which results in a period of high recharge in the spring when evaporation is low. If the spring recharge infiltrates to a sufficient depth, it may not be re-evaporated during the summer and may recharge perched water zones and the Snake River Plain Aquifer. Studies of this phenomenon have been conducted at the Radioactive Waste Management Complex (RWMC) and at the CFA landfills. Data and reports from these two facilities are reviewed and conclusions documented. Comparability of these facilities with conditions at ICPP is evaluated to determine the applicability of the conclusion to the tank farm.

Input to the hydrologic system at ICPP comes from precipitation. Precipitation falling on the ground will infiltrate into the soil. If the rate of precipitation is high, some of the precipitation will not infiltrate, but will flow overland to drainage ditches. For ICPP, runoff only flows to local retention basins where it infiltrates the ground. Therefore, for ICPP, there is no loss of water from the system by runoff, only movement of the point of infiltration. Once in the soil, two things can happen to the water:

- It can be evaporated back into the atmosphere and removed from the system.
- It can continue downward through the soil zone and recharge the aquifer.

The percent of total precipitation that falls into each of these two categories is important to evaluate whether additional sources of water are necessary to form the deep perched water zone under ICPP.

6.1.1 Previous Investigations

No investigations of net infiltration have been conducted at ICPP. A number of investigations have been conducted at the INEL. This section reviews these investigations, evaluates their applicability to

ICPP, and draws a conclusion as to the best estimate of net infiltration at ICPP based on these investigations.

The first estimate of net infiltration at the INEL was conducted by Bruce Schmalz and Wilfred Polzer (Schmalz and Polzer 1969). Soil cores were collected from near the Radioactive Waste Management Complex (RWMC) in clayey silts. Water from the cores was extracted, and tritium analyses made on the extracted soil moisture. Profiles of tritium concentration with depth were developed, and a mass balance between the total activity of tritium input by precipitation compared to the activity in the soil moisture. Based on the mass balance, Schmalz and Polzer concluded that 3.5% of precipitation remained in the soil, with evapotranspiration resulting in the loss to the atmosphere of the remaining 96.5%. At an average precipitation rate of 8.7 in. per year, this provides an estimate of 0.3 in. per year net infiltration.

A similar method to that used by Schmalz and Polzer was used by the U. S. Geological Survey (Cecil et al. 1992) to estimate net infiltration in 1992. In this investigation, soil cores were also collected from fine-grained sediments near the RWMC. Cores were collected from land surface to a depth of about 18 ft. Chlorine-36 and tritium were extracted from the cores, analyzed, and profiles of chlorine-36 and tritium with depth were constructed.

Both chlorine-36 and tritium were generated by atmospheric nuclear testing during the 1950's and 1960's. The peak in chlorine-36 generation occurred in about 1955, corresponding to the peak period of ocean testing of nuclear weapons. The peak in the generation of tritium occurred in 1963. The quantity of soil moisture in the soil between land surface and the peaks in the concentrations of the two radioisotopes was measured. The quantity of moisture remaining in the soil was compared to the total volume of water added through precipitation. Estimates of net infiltration of 0.28 in. per year were obtained for chlorine-36 and 0.14 in. per year were obtained for tritium from the concentration profiles.

An analysis of moisture movement using data obtained from neutron logging of the soil horizon at the RWMC was also performed by Cecil et al. (1992). The estimated net infiltration rate for water calculated from the neutron log data was 0.14 in. per year.

In 1984, an investigation into moisture movement and radionuclide migration at the RWMC was initiated (Mizell, Hull, and Smith 1983). An extensive data set of information on soil moisture content and water transport properties of soils and sedimentary interbeds has been compiled for the RWMC. A recent analysis of these data has been made by Swen Magnuson and Debra McElroy of EG&G Idaho Geosciences^k. The method used by Magnuson and McElroy was to assume steady-state conditions existed at depth (30 ft to 240 ft) below the RWMC. For unsaturated materials, the hydraulic conductivity is a function of moisture content. Given a flux of water, the moisture content will adjust so that the hydraulic conductivity is equal to the flux of water. By measuring the moisture content, and the relation between moisture content and hydraulic conductivity, the flux can be calculated. Calculated fluxes for individual samples ranged over 6 orders of magnitude (6×10^{-5} to 1.5×10^2 in. per year). After reviewing the data, Magnuson and McElroy conclude that the best estimate of flux is between 1.6 and 4 in. per year.

k. Magnuson, S. O., and D. L. McElroy, *Estimation of Infiltration from In Situ Moisture Contents and Representative Moisture Characteristic Curves for the 30 ft, 110 ft and 240 ft Interbeds*, Engineering Design File RWM-93-001.1, August, 1993.

A study of infiltration was made in 1990 at the CFA Landfill II (Miller, Hammel, and Hall 1990). This study was designed to determine the quantity of moisture moving through solid waste buried in the landfill. The approach used was to calculate evaporation losses from weather data collected by NOAA at CFA and to subtract calculated evaporation from precipitation to determine recharge. Soil properties were measured to estimate storage of moisture within the cap material over the buried waste. Net infiltration was calculated from precipitation minus storage minus evaporation. Infiltration was calculated for low-, median-, and high-precipitation years. Infiltration for the median-precipitation year averaged 1.63 in. and ranged from 0.99 to 2.05 in., depending on soil properties.

In 1988, an investigation was made at the CFA landfills of moisture movement using neutron access probes installed in and adjacent to waste at both landfills II and III (Ansley, Hull, and Burns 1988). Data collected for this investigation were not sufficient to estimate net infiltration for the landfills. One observation, however, is important to the understanding of moisture movement in soils. Only data from one 9-month period is presented in the report, from February to August of 1988. This was a very dry period with precipitation about 40% of normal. Neutron probe measurements showed that there was an active zone of drying from land surface to depths ranging from 60 to 84 in. Therefore, the active zone of water flux in sedimentary materials at CFA is on the order of 5 to 7 ft. Infiltration would have to penetrate to a depth greater than this before becoming infiltration. Water held in shallower pores, would mainly be evaporated back to the atmosphere.

6.1.2 Assessment of Applicability

For results of these investigations to be applicable to ICPP, a number of criteria would have to be met. These include:

- Surface materials should have the same moisture-retention characteristics as those at ICPP.
- The scale of the investigation should be roughly the same scale as the area of interest at ICPP.
- For large scale infiltration, characteristics such as impermeable areas and drainage ditches should be taken into account.

Based on these criteria, it is concluded that the studies that involve the movement of tritium and chlorine-36 in surface soils at the RWMC are not applicable to ICPP. Surface soils at the RWMC are clayey silts, while surface soils at ICPP are gravelly sands. Also, the study was conducted at a single point, and does not evaluate spatial averaging effects. Because of the material property differences, the estimates from the tracer tests are probably too low.

Estimates of flux made by Magnuson and McElroy were from data collected at the RWMC. The measurements were made at depth, and so integrate a fairly large area above the measurement point. The RWMC is drained by a series of drainage ditches which collect runoff and concentrate water in certain areas. The RWMC has very little impermeable area such as pavement or buildings. Surface materials at the RWMC are fine-grained, very different than the coarse-grained materials at ICPP. Because these data represent a fairly large area, which integrates a wide range of surface characteristics, the differences in surface materials may be of less importance than for a study

conducted within the dissimilar surface materials. Therefore, the estimates of Magnuson and McElroy are probably reasonable for application to ICPP.

The infiltration study conducted by Miller et al. was based on calculated evapotranspiration, which involves many assumptions. The material properties used in the calculations are probably very similar to those expected at ICPP because both sites are located on alluvium from the Big Lost River. Calculations concentrated on the top 1.5 to 3 ft of sediments. Neutron measurements by Ansley et al. (1988) indicate that the active evapotranspiration zone is more like 5 to 7 ft thick. This would increase the amount of storage in the calculation of net infiltration and decrease the amount of net infiltration. The investigation evaluated an area of 5.9×10^5 ft², which integrates a variety of surface conditions. There are no impermeable areas or drainage ditches at CFA Landfill II. Because of the similarity in material properties and the area of the investigation, the estimates of infiltration from Miller et al. (1990) are considered applicable to ICPP.

6.1.3 Discussion

The estimates of net recharge from Magnuson and McElroy and Miller et al. (1988) range from 1 to 4 in. per year. The average net infiltration from Miller et al. of 1.63 in. per year is considered to be the best estimate of net infiltration for use at ICPP. Because of impermeable areas and a drainage system that collects runoff in infiltration ponds, the total infiltration from the ICPP area may be larger. The spatial distribution of that infiltration, however, would not be uniform. Flat areas would have infiltration rates similar to those determined for the CFA landfills. Infiltration would increase along drainage ditches, and be greatest of all beneath infiltration ponds used to collect runoff.

6.2 Infiltration from Drainage Ditches

One mechanism for water to reach tank vaults at the tank farm is for water from drainage ditches, lawn watering, or leaking pipes to the south and east of the tank farm to infiltrate through sediments to the vaults. A dye tracer placed beyond the margin of the tank farm membrane was detected in the cold sumps for tanks WM-189 and WM-190. Therefore, there is evidence of lateral migration in the subsurface. Figure 6.1 shows a cross-section through the tank farm and an enlargement of the relationship between vault 713 and the lawn west of building CPP-699. The elevation of the top of vault 713 is about 4908 ft, the elevation of the sidewalk in back of CPP-699 is about 4911.5 ft, the elevation of the end of the membrane is estimated to be about 4912.5 ft. Underground utility pipes are generally buried 6 to 8 ft below ground to prevent freezing in the winter, and therefore are most likely at an elevation of 4906 ft or less. The distance from places where water could be introduced to the subsurface are between 20 ft (edge of the membrane) and 60 ft from the vault. This creates a very low gradient between these possible sources and the vault.

To evaluate the potential for water to spread laterally during infiltration a simple analytical model for infiltration from a drainage ditch was used. Results of this simple calculation provide some insight into the mechanisms for lateral movement of water. An evaluation of the amount of lateral spreading associated with seepage from a drainage ditch has been performed using an equation presented by Harr (1962) and based on Vedernikov (1934). In order for soil adjacent to the tank vaults to release water to the vaults, saturated conditions must occur in the soil. If the soil is unsaturated, negative soil pressures would prevent the release of water to openings significantly larger than the soil pore spaces. For this analysis, it is assumed that saturated conditions occur within a homogeneous aquifer below a drainage ditch.

FIGURE 6.1
**CROSS-SECTION THROUGH THE
 HLLW TANK FARM**
 WINCO/PERCHED WATER SUPPORT/ID

For seepage from a trapezoidal-shaped ditch, the maximum width of flow (L) below the ditch is:

$$L = B + AH$$

where:

B	=	The width of the water surface in the ditch,
A	=	a constant based on the side slope angle of the ditch, and
H	=	The height of water in the ditch.

For seepage from a triangular-shaped ditch with 1:1 side slopes, the above equation reduces to:

$$L = 3H$$

This equation predicts that the maximum amount of lateral spreading below a drainage ditch is three times the height of water in the ditch, and the spreading from the center line of the ditch on the height of water in the ditch and is not dependent on hydraulic conductivity. The incorporation of uniform anisotropy in hydraulic conductivity would not affect the estimated amount of lateral spreading.

The above equation suggests that under uniform hydrogeologic conditions, significant lateral spreading away from a drainage ditch would not be expected. To achieve a saturated zone extending 20 feet away from the center-line of a ditch, the height of water in the ditch would have to be at least 13 feet. As noted above, in order to get groundwater flow into the tank vault, saturated conditions must occur adjacent to the vault. To achieve 20 feet or more of lateral spreading from a ditch with subsequent flow into a tank vault, it is expected that the non-homogenous conditions and a perched saturated zone would need to be present.

6.3 Water Balance for the Tank Farm

The overall water balance for the tank farm is estimated based on precipitation records, drainage patterns, and pumpage from the tank farm vaults. This provides an assessment of water available for leakage into vaults and for potential transport of contaminants from sediments within the tank farm to deep perched water.

6.3.1 Comparison of Regression Estimates to Jetting Data

The regression analysis of patterns in tank farm seepage was based on the inches of seepage into the vault. Coefficients estimated from the regression are also in terms of inches. However, if it can reasonably be assumed that there is a linear relation between the inches of water in a sump or vault, and the volume of water, the coefficients can be used to estimate the volume of water from different sources. For most of the sumps, the water level stays either within the sump or within the vault throughout the study period. Rating curves giving the relation between inches of water and volume of water are provided in ICPP Chemical Plant Operating Procedure 4.3.5.5, "Tank Farm Sumps - High Level Alarm Response." Table 6.1 shows the rating constants and seepage volumes for the tank farm sumps estimated from the regression coefficients.

Column 3 in Table 6.1 indicates the volume of water per month that seeps into the sumps from a constant source. It is calculated from C_0 in Table 4.4 and the sump or vault rating constant in column 2 of Table 6.1. Recharge response is calculated from C_1 in Table 4.4 and the sump or vault rating constant. This is the volume of water expected from 1 in. of precipitation. To calculate the predicted

monthly seepage, the constant source volume is added to the average monthly recharge volume. Average monthly recharge volume is calculated by multiplying the recharge response volume times the square of the average monthly precipitation. The final column in Table 6.1 shows the average monthly volume jetted from each sump calculated from Table 2.4.

Based on this summarization of data across all sumps, approximately 47% of the total seepage into the tank farm vaults (1,066/2,281 gal) comes from a constant source of water. Approximately 41% ($1,759 \cdot (8.72/12)^2 / 2,281$ gal) is derived from infiltration of precipitation, and about 12% is from miscellaneous and random sources. Because not all of the sumps were included in the regression analysis, there is a maximum uncertainty in these estimated percentages of $\pm 4\%$. These percentages can be used to estimate the volume of water that a source would need to contribute to account for seepage into the tank farm. This calculation will use the average annual volume of water jetted from the tank farm as a basis, 29,676 gal per year.

For the constant source:

$$0.47 * 29,676 \text{ gal} = 13,950 \text{ gal per year}$$

For the infiltration of precipitation:

$$0.41 * 29,676 = 12,170 \text{ gal per year}$$

And for miscellaneous sources:

$$0.12 * 29,676 = 3,560 \text{ gal per year}$$

Table 6.1 Average monthly volumes of seepage water for sumps predicted from regression models.

Sump	Rating constant (gal/in.) ^a	Constant source (gal/mo)	Recharge response (gal/1 in.)	Predicted monthly seepage (gal) ^b	Average monthly jetting (gal) ^c
183 N	0.6	0	0.3	0.16	0
184 N	0.6	0	0.04	0.02	0
185 S	700	0	310	164	117
186 S	700	0	168	89	137
187 S	700	127	440	359	431
188 N	700	143	397	353	436
189 C	9.4	143	71	180	363
189 S	113	479	296	635	471
190 C	9.4	173	77	214	320
190 S	0.6	0.6	0.2	0.7	5.7
Total		1,066	1,760	1,995	2,281 ^d

a. From Chemical Plant Operating Procedure 4.3.5.5

b. Calculated from $\text{Constant} + (8.72/12)^2 * \text{Recharge}$. Recharge is multiplied by the square of the average monthly precipitation to determine the average monthly volume from recharge.

c. Calculated from Table 2.4.

d. This is the sum for the sumps included in the regression analysis. The total for all sumps is 2,473 gal as shown in Table 2.4. This volume is 92% of the total volume of water jetted. Therefore, conclusions based on the modeled sumps should account for essentially all of the seepage water.

6.3.2 Volume of water needed to support a deep perched water zone

A number of perched water bodies exist below ground level at the ICPP. Perched water occurs when a sufficient amount of water moves downward through a higher conductivity zone and encounters a lower conductivity zone. This lower conductivity zone can be a fine-grained sedimentary interbed, a massive basalt flow, or the upper surface of a basalt flow where the fractures and pores have been filled with fine-grained sediments and secondary minerals. Therefore, "perching" of water often takes place within and above the interbeds where enough water is being recharged through the basalt. The most significant perching layer at ICPP is believed to exist approximately 110 ft below ground surface. Two areas of perched water have been identified on the 110 ft interbed.

One perched water body occurs beneath the ICPP percolation ponds, immediately south of the facility. A second area of perched water occurs under the northern portion of the plant. Perched water is found in a number of wells, but the zone does not appear to be continuous. This zone underlies a number of ICPP facilities, such as the tank farm. For the southern perched water zone, there is a clear source of water from the percolation ponds. For the northern perched water zone, there is no such obvious source. This has led to speculation that releases of water from leaky pipes is responsible for the perched water under the northern portion of ICPP.

The perched water zones at ICPP were investigated by Norrel et al. (1993) and the volume of recharge needed to support the northern perched water zone was made. The estimated flux to the northern perched water zone was 781,000 gal per day. There is a great deal of uncertainty in this estimate, particularly with respect to the geometry of the perched water zone. A sensitivity analysis was performed to assess the effect of the uncertainty on the flux. The conclusion of the uncertainty analysis was that the flux could vary over a wide range of values, but that it did not drop below about 100,000 gal per day unless unrealistic values were used in the calculation. Therefore, while the volume of water needed to support the northern perched water zone is not known with any degree of certainty, it is likely to be in the range of 200,000 to 800,000 gal per day ($7.3\text{E}+07$ to $2.9\text{E}+08$ gal per year).

6.3.3 Volumes of Water Available from Precipitation

In this section, the volumes of water from precipitation available for infiltration to tank farm vaults and support of a deep perched water are estimated. The average annual precipitation at ICPP is 8.72 in. (0.73 ft) (Clawson et al. 1989) and the net infiltration estimated to be 1.63 in. (0.14 ft). Because of the many unpermeable areas within the ICPP facility (roofs, roadways) a significant fraction of the total precipitation input runs off to drainage ditches. The drainage ditches are unlined and a significant fraction of the infiltration likely occurs along these ditches. It is beyond the scope of this report to provide a detailed spatial evaluation of infiltration. The amount of infiltration can be bounded and compared to estimates of seepage to vaults and the deep perched water.

The total surface area of the tank farm is 100,000 ft². About 30,000 ft² at the western end of the tank farm drains to Beech Street. The remaining 70,000 ft² drains to the east. Table 6.2 shows the volume of water that could be generated from precipitation falling on the tank farm. The estimated seepage of precipitation into tank farm vaults from the regression analysis is 12,170 gal per year. Comparing this to quantities in Table 6.2 indicates that only 2 to 11% of available precipitation is necessary to account for precipitation infiltration to the tank farm. The precipitation falling on the tank farm, even accounting for evaporation, is four times the total volume of water pumped from the

sumps and eight times the volume estimated to be derived from precipitation. Therefore, precipitation is more than adequate to support the observed seepage into the tank farm vaults.

To determine whether precipitation is adequate to support the deep perched water zone, the total volume of precipitation falling on the northern end of ICPP was estimated. The volume of water probably falls near the low end of the range $4.0\text{E}+06$ to $2.075\text{E}+07$ gal per year. The estimated range of infiltration needed to support the perched water body is $7.3\text{E}+07$ to $2.9\text{E}+8$ gal per year (Norrel et al. 1993). Therefore, even if all precipitation falling on the northern end of ICPP was converted to recharge, the volume of precipitation falls below the range of volumes needed to sustain the deep perched water zone. The estimated volumes of water available from infiltration are so much smaller than the estimates of water needed to sustain the deep perched water zone, that alternative sources of water are indicated.

6.4.3 Volumes of Water Available from Lawn Watering

The last four summers have generally been very dry. It is a reasonable assumption that approximately 3,000 gal per day (Section 3.1.3) of water have been added to the lawn during the summer for the study period. The lawn is watered from mid-April to mid-October, or about 180 days per year. The total volume of water used for lawn watering is therefore about 540,000 gal per year. The estimated volume of water from the constant source is estimated to be 13,950 gal per year (Section 6.3.1). This is about 3% of the water available from lawn watering, so this source is capable of providing the volume of water observed in the sumps.

Table 6.2 Annual volumes of water from precipitation and net infiltration.

<u>Tank Farm</u>		
Area	Total Volume @ 0.73 ft/yr	Net infiltration volume @ 0.14 ft/yr
100,000 ft ²	546,000 gal	104,700 gal
<u>Adjacent Runoff Zones</u>		
Area	Total Volume (gal) @ 0.73 ft/yr	Net infiltration volume @ 0.14 ft/yr
211,400 ft ²	1,154,300 gal	221,380 gal
<u>Northern End of ICPP</u>		
Area	Total Volume @ 0.73 ft/yr	Net infiltration volume @ 0.14 ft/yr
3.8E+06 ft ²	2.075E+07 gal	4.0E+06 gal

7. CONCLUSIONS

This section summarizes the findings of this investigation and presents the conclusions. The objective of this report is to identify sources of seepage into the vaults at the HLLW tank farm. In Section 3, a conceptual model was presented that identified potential sources of seepage. Characteristics of those sources were described in Table 3.1. In Section 4, patterns in seepage were analyzed. Section 5 evaluated the water chemistry from two of the sumps to compare to potential sources. The volumes of water in seepage and from various sources were evaluated in Section 6.

7.1 Evaluation of Hypotheses

Characteristics of the sumps have been determined in this investigation to compare to characteristics hypothesized from various sources. This information is summarized in Table 7.1. Four patterns were identified in sump seepage.

- Continuous seepage
- Response to recharge
- Seasonal cycles
- Random variation.

The volumes of water associated with continuous seepage, recharge, and random variation were quantified. There is no specific volume of water associated with the seasonal cycle, all it does is change the response over time about a mean value. When dealing with annual averages, it is the mean value that is of interest, not the seasonal variation in the monthly responses. Based on the volume estimates for the various types of seepage, quite a few of the sources could be eliminated as not being able to provide sufficient volume of water. A number of man-made sources, however, are capable of providing the volumes of water associated with continuous seepage.

The chemistry of water in sumps 189 C and 190 C turned out to provide extremely valuable information. Detection limits for these analyses were very high because of the small sample volume, and so there is a great deal of uncertainty in these conclusions. The chemistry of water in the sumps could be related to the chemistry of water from a number of man-made sources; particularly raw water and potable water. There were also a number of chemical species in the water that suggested the addition of chemicals commonly found in fertilizer. Of the man-made sources, this would be most consistent with watering the lawn in back of building CPP-699 as a source.

7.2 Conclusions

Based on the analysis of seepage into tank farm vaults, the two most important sources of seepage are infiltration of precipitation and watering the lawn in back of CPP-699. Infiltration of precipitation was a source of seepage for every vault except WM-181, which showed no seepage during the study period. The volume of water falling on the tank farm as precipitation is more than adequate to provide the volume of water attributable to infiltration. The most likely pathway for this water is seepage through the membrane at some of the many perforations made for pipes, risers, and valve boxes. Once on top of the vault, water can seep through joints in the roof. Approximately 41% of the water seeping into the tank farm is from this source.

The second most important source of seepage for the tank farm vaults is the watering of the lawn in back of CPP-699. While the volume of water from this source is slightly larger than that from

Table 7.1 Discussion of sources hypothesized to generate seepage into the HLLW tank farm vaults.

Source and Release	Characteristics				Conclusion
	Pattern	Chemical	Location	Volume	
Valve seals in waste transfer lines leak to secondary containment or waste transfer lines leak to secondary containment	Occurs only when waste transfers take place. Tied to NWCF operations. Consider to be random over time.	Depends on waste transfer. Very high TDS and radionuclide concentrations. Tables 2.1 and 2.2 give typical values.	Any vault that receives input from secondary containment lines.	Uncertainty in transfer volume is $\pm 5\%$. Absolute volume depends on transfer volume. Even if leak doesn't reach vault, about 100 gal of water used to decon line before repair.	This source is a known contributor of very small volumes of HLLW to the sumps and small quantities of decontamination solution when valves are fixed. The total contribution from this source is very small, and very rare. Therefore, while some sump seepage is attributable to leaking valve seals in waste lines, this is not a significant source of water to the sumps.
	Regression analysis indicated that from 11 to 85% of the total variation in data was from random sources.	Radiation monitors have detected releases to valve boxes. Chemistry of water in 189 C and 190 C does not reflect HLLW.	No special location information.	Volumes of water for random sources average about 300 gal per month.	
HLLW tank leaks directly to a vault	Depends on tank operating history. Assume fluctuation about an average continuous rate.	Depends on tank contents. Very high TDS and radionuclide concentrations. Tables 2.1 and 2.2 give typical values.	Could be any vault except 713/190 because tank 190 is empty.	Volume that could leak and not be detected is 200 gal. Greater than this would be detected by tank level monitoring.	A leaking HLLW tank would introduce extremely high concentrations of radionuclides and chemicals into sump water. Monitoring of water levels in the tanks would show any loss and a trend would be quickly detected. Therefore, there is no evidence of a HLLW tank leaking, and tank leaking could not be a significant source of water to the sumps.
	Only tanks in vault 713 show continuous seepage. Pattern of continuous seepage not found in records for most vaults.	Radiation monitors would detect even small quantities of HLLW when a sump was jettied. Chemistry of 189 C and 190 C not HLLW.	Any vault could be leaking, no special source location.	Volume of water for continuous sources averages about 1,000 gal/mo.	

Table 7.1 (Continued).

Source and Release	Characteristics				Conclusion
	Pattern	Chemical	Location	Volume	
Steam valve leaks into vault or vault sump	Leaking steam valves are readily detected during routine maintenance operations. Would not expect valve to leak undetected for long periods. Pattern would be random over time.	Steam would have no dissolved solids or radionuclides.	All vaults have steam lines for jetting sumps or tanks.	Leakage to vaults or tanks of up to 100 gal has occurred in the past.	Leaks through steam valves has occurred in the past and will likely occur again. This type of leak is easily detected and fixed. The potential volume is small and cannot account for the volumes of water jetted from tank farm sumps. Leaking steam valves is not considered to be a significant source of seepage into sumps.
	Regression analysis indicates from 11 to 85% of variation is from random sources.	Sumps show significant levels of dissolved solids.	No special location.	Volume of water from random sources averages about 300 gal/mo.	
Steam condensate is released to land surface over tank farm	The steam lines are shut off at times, but are usually left on. Input continuous.	Steam would have no dissolved solids or radionuclides. Could pick up small amounts of both infiltrating through surface soils.	Steam vents to the surface are located at CPP-628, CPP-635, and CPP-636. This could be a source for vault 713 (all four chambers) and vaults 782 and 783 next to CPP-628.	Volume of water at the surface is estimated to be 5 gal/month.	The volume of water available from this source is much too small to account for the volume of water jetted from vault 713. This cannot be a significant source of water to the sumps.
	Sumps in vault 713 show evidence of continuous input of water.	Dissolved salts in sumps in vault 713 are higher than would be expected from steam	Sumps with continuous seepage have steam discharge to surface.	Volume of continuous seepage averages about 1,000 gal/mo.	

Table 7.1 (Continued).

Source and Release	Characteristics				Conclusion
	Pattern	Chemical	Location	Volume	
HLLW tank cooling water leaks to vaults	Water is present in the lines all the time, even though the lines are currently not in use. A small leak would provide a continuous input.	Cooling water is demineralized water with 500 mg/L of potassium dichromate added as corrosion inhibitor.	Three tanks do not have cooling coils, 181, 184 and 186. Vaults 781, 784, and 786 could not have this source.	No historical data. System has pressure-drop alarm, so volume lost would be small.	Sump water samples do not show the quantities of chromium that would be expected if this was the source of water. The volumes of water found in most vaults is sufficient to cause a noticeable change in the volume in the cooling water system. This is not a source of water to the sumps.
	Most vaults show no evidence of a continuous leak.	Water chemistry in 189 C and 190 C have K/Cr ratio that is inconsistent with this source.	Cooling coils are present in vaults with continuous seepage.	Volume of continuous seepage averages about 1,000 gal/mo.	
Service waste lines leak to surficial sediments	Seepage would be continuous on the time scale of a month.	Composition would be highly variable depending on waste stream.	Service waste lines run along the northern, the western, and the southwestern boundaries of the tank farm.	Volume highly variable depending on flow rate in pipe.	The location of waste lines with respect to the vault with the most continuous seepage makes this a very unlikely source for seepage into sumps.
	Sumps in vault 713 show continuous seepage.	No information to limit chemistry.	Vault with continuous seepage is at the east end, and not near service waste lines.	Volume of continuous seepage into 713 is about 1,000 gal/mo.

2 of 2

Table 7.1 (Continued).

Source and Release	Characteristics				Conclusion
	Pattern	Chemical	Location	Volume	
Potable water line leaks to surficial sediments	The seepage would be continuous.	The composition of seepage would be the same as potable water.	A potable water line runs to building CPP-699, immediately east of the tank farm.	A leak of any magnitude in this line would likely be detected due to wet soil above the leak (ie. like the leak near the cafeteria).	The characteristics of the potable water line make it a possible source of seepage to vault 713. The pattern, chemistry, location, and volume are all consistent with observations.
	Vault 713 shows continuous seepage.	Conservative chemical species in sumps 189 C and 190 C are very similar to potable water.	The vault with the most continuous seepage is immediately adjacent to the potable water line.	The volume of continuous seepage is 1,000 gal/mo, or about 0.02 gal/min. This is a small leak and could go undetected.	
Sewage waste line leaks to surficial sediment	The input would be continuous.	The water would be high in TDS and organic carbon. Bacteria might also be present.	Sewage waste lines run past the west end of the tank farm and to the lift station north of the tank farm.	Volume highly variable depending on flow rate in pipe.	The chemistry and location make sewer lines an unlikely source of seepage into the tank farm vaults.
	Vault 713 shows a continuous input.	Chemistry of water in 189 C and 190 C too low in TDS and organic carbon for this source. No coliform bacteria detected.	Lines are fairly far from the tank farm. No lines close to vault 713.	Volume of water in sewage lines is adequate to account for seepage.	

Table 7.1 (Continued).

Source and Release	Characteristics				Conclusion
	Pattern	Chemical	Location	Volume	
Fire water line leaks to surficial sediment	The input would be continuous.	The water would have the same composition as raw water.	A fire water line runs along the southeast boundary of the tank farm.	A leak of any magnitude would be detected by wet soil above the leak (ie. like leak in sprinkler line at CPP-699).	The characteristics of the fire-water line make it a possible source of seepage to vault 713. The pattern, chemistry, location, and volume are all consistent with observations.
	Vault 713 shows continuous inputs.	Conservative species in sumps have similar concentration as raw water.	The vault with the most continuous seepage is vault 713 at the east end of the tank farm.	The volume of continuous seepage is about 1,000 gal/mo or 0.02 gal/min. This small leak could go undetected.	
Lawn sprinklers spray water on the lawn	Watering the lawn would produce a seasonal pattern with a maximum in the late summer or early fall, and a minimum in winter.	The water would have the same composition as raw water.	Vaults at the east end of the tank farm would be most susceptible.	Volume of water ranges from 21,000 gal/mo to 90,000 gal/mo. in summer and fall.	The characteristics of the lawn watering make it the most likely source of seepage to vault 713. The pattern, chemistry, location, and volume are all consistent with observations.
	Sumps in 713 show a phase shift in seasonal cycle consistent with a late summer maximum.	Conservative species in sump have similar composition as raw water. Fertilizer species show increased concentration.	Only vault with significant continuous seepage and phase shift are at east end of tank farm.	Volume of water from continuous seepage averages 1,000 gal/mo.	

Table 7.1 (Continued).

Source and Release	Characteristics				Conclusion
	Pattern	Chemical	Location	Volume	
Precipitation falls on tank farm and infiltrates through gaps in the liner and/or moves laterally from drainage ditches	Input would occur whenever there was significant precipitation. Low soil moisture conditions could affect this by intercepting the precipitation. Some seasonal component due to evaporation.	The water would pick up small quantities of dissolved solids and radionuclides in surface soils.	Any tank with risers and valve boxes on top would be subject to infiltration. Tanks with flat roofs would be more susceptible. Tanks at east end would be more susceptible because the tank farm surface drains west to east. Drainage ditches adjacent to east and southeast boundaries.	Average net recharge estimated between 0.4 in. and 2 in. per year. From 100,000 ft ² tank farm can have from 100,000 gal to 550,000 gal per year.	The pattern of seepage clearly indicates that infiltration of precipitation is a significant source of seepage into sumps. For all the octagonal vaults, essentially all of the seepage comes from this source.
	All vaults with seepage showed significant coefficients for recharge response.	Sump chemistry was closer to raw water. Sump sample collected in summer would not necessarily reflect spring recharge if sump had been emptied in between.	Vaults that show response to recharge tend to be vaults with flat roofs rather than hunched roofs. More recharge response on east end of tank farm. Surface drains west to east.	Volume of water from recharge averages 930 gal/mo or 11,150 gal/yr.	

precipitation (47% of the total), it only affects one vault. There are a number of possible sources for the continuous seepage into vault 713 at the eastern end of the tank farm. Watering the lawn was identified as the most likely source because of the phase shifts in the seasonal cycles for sumps in vault 713, because of the fertilizer related chemicals in the water in sumps 189 C and 190 C, and because no release mechanism has to be postulated – the water is sprayed on the lawn every night for about six months of the year.

The pathway for water used on the lawn to reach the vault sumps is not so obvious. Calculations show that infiltration should move primarily downward, with very little spreading, in a homogeneous system. The sediments in the tank farm are not homogeneous, but a perching layer would have to develop very near the surface to induce lateral flow from the lawn to the tank farm. There may be a very low permeability layer in the subsurface at the east end of the tank farm that permits water to flow onto the vaults. Once on top of the vault, water has been observed from inside the vault to leak through joints in the roof. A second possibility is that water is entering the vault through the drainage channels associated with the HLLW pipe containments. HLLW pipes lead from vault 713 to both the old and new waste calciner buildings. Water may be able to enter the containments, flow along the containment to sampling stations in valve boxes, and then back into the vaults in the drain lines. There is not sufficient information to clearly define the pathway into the vault for water from lawn watering.

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Appendix A

**Time Series Plots of
Water levels in Sumps**

23-JUL-1993 12:34:40 WPCS::
Sump Level WM-188S 1-JAN-89

Option:

23-JUL-1993 13:04:02 WPCS::
Sump Level WM-188S 1-JUL-89

Option:

23-JUL-1993 14:44:10 WPCS::
Sump Level WM-188S 1-JAN-90

Option:

26-JUL-1993 08:16:33 WPCS::
Sump Level WM-180S 1-JUL-90

Option:

26-JUL-1993 09:25:47 WPCS::
Sump Level WM-180S 1-JAN-91

Option:

26-JUL-1993 09:51:22 WPCS::
Sump Level WM-180S 1-JUL-91

Option:

23-JUL-1993 10:31:47 WPCS::
 Sump Level WM-188S 1-JAN-92

Option:

19-JUL-1993 09:22:02 WPCS::
 Sump Level WM-188S 1-JUL-92

Option:

19-JUL-1993 09:48:19 WPCS::
 Sump Level WM-188S 1-JAN-93

Option:

23-JUL-1993 12:36:29 WPCS::
Sump Level WM-181S 1-JAN-89

Option:

23-JUL-1993 13:05:39 WPCS::
Sump Level WM-181S 1-JUL-89

Option:

23-JUL-1993 14:47:43 WPCS::
Sump Level WM-181S 1-JAN-90

Option:

26-JUL-1993 08:18:09 WPCS::
Sump Level WM-1B1S 1-JUL-90

Option:

26-JUL-1993 09:29:36 WPCS::
Sump Level WM-1B1S 1-JAN-91

Option:

26-JUL-1993 09:53:44 WPCS::
Sump Level WM-1B1S 1-JUL-91

Option:

23-JUL-1993 10:33:18 WPCS::
Sump Level WM-181S 1-JAN-92

Option:

19-JUL-1993 09:23:23 WPCS::
Sump Level WM-181S 1-JUL-92

Option:

19-JUL-1993 09:49:42 WPCS::
Sump Level WM-181S 1-JAN-93

Option:

23-JUL-1993 12:38:01 WPCS::
 Sump Level WM-182S 1-JAN-89

Option:

23-JUL-1993 13:07:05 WPCS::
 Sump Level WM-182S 1-JUL-89

Option:

23-JUL-1993 14:49:07 WPCS::
 Sump Level WM-182S 1-JAN-90

Option:

26-JUL-1993 08:19:39 WPCS::
 Sump Level WM-182S 1-JUL-90

Option:

26-JUL-1993 09:31:21 WPCS::
 Sump Level WM-182S 1-JAN-91

Option:

26-JUL-1993 09:55:27 WPCS::
 Sump Level WM-182S 1-JUL-91

Option:

23-JUL-1993 10:35:06 WPCS::
 Sump Level WM-182S 1-JAN-92

Option:

19-JUL-1993 09:25:00 WPCS::
 Sump Level WM-182S 1-JUL-92

Option:

19-JUL-1993 09:51:09 WPCS::
 Sump Level WM-182S 1-JAN-93

Option:

23-JUL-1993 12:46:39 WPCS::
 Sump Level WM-183N 1-JAN-89

Option:

23-JUL-1993 13:08:47 WPCS::
 Sump Level WM-183N 1-JUL-89

Option:

23-JUL-1993 14:50:27 WPCS::
 Sump Level WM-183N 1-JAN-90

Option:

26-JUL-1993 08:22:35 WPCS::
Sump Level WM-183N 1-JUL-90

Option:

26-JUL-1993 09:32:48 WPCS::
Sump Level WM-183N 1-JAN-91

Option:

26-JUL-1993 09:57:01 WPCS::
Sump Level WM-183N 1-JUL-91

Option:

23-JUL-1993 10:52:14 WPCS::
Sump Level WM-183N 1-JAN-92

Option:

19-JUL-1993 09:26:45 WPCS::
Sump Level WM-183N 1-JUL-92

Option:

19-JUL-1993 09:52:30 WPCS::
Sump Level WM-183N 1-JAN-93

Option:

23-JUL-1993 12:49:32 WPCS::
 Sump Level WN-1B4N 1-JAN-89

Option:

23-JUL-1993 13:10:12 WPCS::
 Sump Level WN-1B4N 1-JUL-89

Option:

23-JUL-1993 14:51:48 WPCS::
 Sump Level WN-1B4N 1-JAN-90

Option:

26-JUL-1993 08:42:27 WPCS::
 Sump Level WM-1B4N 1-JUL-90

Option:

26-JUL-1993 09:34:16 WPCS::
 Sump Level WM-1B4N 1-JAN-91

Option:

26-JUL-1993 09:58:30 WPCS::
 Sump Level WM-1B4N 1-JUL-91

Option:

23-JUL-1993 18:54:29 WPCS::
 Sump Level WM-184N 1-JAN-92

Option:

19-JUL-1993 09:28:16 WPCS::
 Sump Level WM-184N 1-JUL-92

Option:

19-JUL-1993 09:54:06 WPCS::
 Sump Level WM-184N 1-JAN-93

Option:

23-JUL-1993 12:51:01 WPCS::
 Sump Level WM-1855 1-JAN-89

Option:

23-JUL-1993 13:11:34 WPCS::
 Sump Level WM-1855 1-JUL-89

Option:

23-JUL-1993 14:53:34 WPCS::
 Sump Level WM-1855 1-JAN-90

Option:

26-JUL-1993 08:46:53 WPCS::
 Sump Level WM-185S 1-JUL-90

Option:

26-JUL-1993 09:35:53 WPCS::
 Sump Level WM-185S 1-JAN-91

Option:

26-JUL-1993 10:00:01 WPCS::
 Sump Level WM-185S 1-JUL-91

Option:

23-JUL-1993 10:57:39 WPCS::
 Sump Level WM-185S 1-JAN-92

Option:

19-JUL-1993 09:29:56 WPCS::
 Sump Level WM-185S 1-JUL-92

Option:

19-JUL-1993 10:09:47 WPCS::
 Sump Level WM-185S 1-JAN-93

Option:

23-JUL-1993 12:52:32 WPCS::
 Sump Level WM-186S 1-JAN-89

Option:

23-JUL-1993 13:14:15 WPCS::
 Sump Level WM-186S 1-JUL-89

Option:

23-JUL-1993 15:05:05 WPCS::
 Sump Level WM-186S 1-JAN-90

Option:

26-JUL-1993 08:51:48 WPCS::
Sump Level WM-186S 1-JUL-90

Option:

26-JUL-1993 09:37:21 WPCS::
Sump Level WM-186S 1-JAN-91

Option:

26-JUL-1993 10:01:30 WPCS::
Sump Level WM-186S 1-JUL-91

Option:

23-JUL-1993 10:59:08 WPCS::
Sump Level WM-186S 1-JAN-92

Option:

19-JUL-1993 09:31:15 WPCS::
Sump Level WM-186S 1-JUL-92

Option:

19-JUL-1993 10:11:23 WPCS::
Sump Level WM-186S 1-JAN-93

Option:

23-JUL-1993 12:54:09 WPCS::
 Sump Level WM-1B/S 1-JAN-89

Option:

23-JUL-1993 13:19:52 WPCS::
 Sump Level WM-1B/S 1-JUL-89

Option:

23-JUL-1993 15:06:35 WPCS::
 Sump Level WM-1B/S 1-JAN-90

Option:

Sump Level WM-187S 1-JUL-90

26-JUL-1993 09:39:24 WPCS::
Sump Level WM-187S 1-JAN-91

Option:

26-JUL-1993 10:03:14 WPCS::
Sump Level WM-187S 1-JUL-91

Option:

23-JUL-1993 11:00:37 WPCS::
Sump Level WM-187S 1-JAN-92

Option:

19-JUL-1993 09:32:50 WPCS::
Sump Level WM-187S 1-JUL-92

Option:

19-JUL-1993 10:12:51 WPCS::
Sump Level WM-187S 1-JAN-93

Option:

23-JUL-1993 12:55:39 WPCS::
 Sump Level WM-188N 1-JAN-89

Option:

23-JUL-1993 13:21:15 WPCS::
 Sump Level WM-188N 1-JUL-89

Option:

23-JUL-1993 15:08:48 WPCS::
 Sump Level WM-188N 1-JAN-90

Option:

26-JUL-1993 08:53:52 WPCS::
 Sump Level WM-188N 1-JUL-90

Option:

26-JUL-1993 09:40:45 WPCS::
 Sump Level WM-188N 1-JAN-91

Option:

26-JUL-1993 10:04:41 WPCS::
 Sump Level WM-188N 1-JUL-91

Option:

23-JUL-1993 11:02:17 WPCS::
 Sump Level WM-188N 1-JAN-92

Option:

19-JUL-1993 09:34:15 WPCS::
 Sump Level WM-188N 1-JUL-92

Option:

19-JUL-1993 10:17:55 WPCS::
 Sump Level WM-188N 1-JAN-93

Option:

23-JUL-1993 12:57:39 WPCS::
 Sump Level WM-189C 1-JAN-89

Option:

23-JUL-1993 13:22:39 WPCS::
 Sump Level WM-189C 1-JUL-89

Option:

23-JUL-1993 15:10:41 WPCS::
 Sump Level WM-189C 1-JAN-90

Option:

26-JUL-1993 00:57:43 WPCS::
Sump Level WM-189C 1-JUL-90

Option:

26-JUL-1993 09:42:10 WPCS::
Sump Level WM-189C 1-JAN-91

Option:

26-JUL-1993 10:06:10 WPCS::
Sump Level WM-189C 1-JUL-91

Option:

23-JUL-1993 11:03:43 WPCS::
Sump Level WM-189C 1-JAN-92

Option:

19-JUL-1993 09:35:57 WPCS::
Sump Level WM-189C 1-JUL-92

Option:

19-JUL-1993 10:19:22 WPCS::
Sump Level WM-189C 1-JAN-93

Option:

23-JUL-1993 12:59:11 WPCS::
Sump Level WM-189S 1-JAN-89

Option:

23-JUL-1993 14:28:02 WPCS::
Sump Level WM-189S 1-JUL-89

Option:

26-JUL-1993 08:06:09 WPCS::
Sump Level WM-189S 1-JAN-90

Option:

26-JUL-1993 08:59:53 WPCS::
 Sump Level WM-189S 1-JUL-90

Option:

26-JUL-1993 09:43:50 WPCS::
 Sump Level WM-189S 1-JAN-91

Option:

26-JUL-1993 10:07:45 WPCS::
 Sump Level WM-189S 1-JUL-91

Option:

23-JUL-1993 11:05:15 WPCS::
 Sump Level WM-189S 1-JAN-92

Option:

19-JUL-1993 09:37:25 WPCS::
 Sump Level WM-189S 1-JUL-92

Option:

19-JUL-1993 10:21:02 WPCS::
 Sump Level WM-189S 1-JAN-93

Option:

23-JUL-1993 13:00:35 WPCS::
 Sump Level WM-1900 1-JAN-89

Option:

23-JUL-1993 14:30:01 WPCS::
 Sump Level WM-1900 1-JUL-89

Option:

26-JUL-1993 08:07:57 WPCS::
 Sump Level WM-1900 1-JAN-90

Option:

26-JUL-1993 09:01:13 WPCS::
 Sump Level WM-1900 1-JUL-90

Option:

26-JUL-1993 09:45:14 WPCS::
 Sump Level WM-1900 1-JAN-91

Option:

26-JUL-1993 10:09:09 WPCS::
 Sump Level WM-1900 1-JUL-91

Option:

23-JUL-1993 11:07:54 WPCS::
 Sump Level WM-198C 1-JAN-92

Option:

19-JUL-1993 09:39:03 WPCS::
 Sump Level WM-198C 1-JUL-92

Option:

19-JUL-1993 10:22:35 WPCS::
 Sump Level WM-198C 1-JAN-93

Option:

23-JUL-1993 13:02:10 WPCS::
 Sump Level WM-190S 1-JAN-89

Option:

23-JUL-1993 14:31:45 WPCS::
 Sump Level WM-190S 1-JUL-89

Option:

26-JUL-1993 00:09:40 WPCS::
 Sump Level WM-190S 1-JAN-90

Option:

26-JUL-1993 09:02:49 WPCS::
Sump Level WM-190S 1-JUL-90

Option:

26-JUL-1993 09:47:01 WPCS::
Sump Level WM-190S 1-JAN-91

Option:

26-JUL-1993 10:12:22 WPCS::
Sump Level WM-190S 1-JUL-91

Option:

23-JUL-1993 11:09:21 WPCS::
 Sump Level WM-190S 1-JAN-92

Option:

19-JUL-1993 09:40:31 WPCS::
 Sump Level WM-190S 1-JUL-92

Option:

19-JUL-1993 10:23:55 WPCS::
 Sump Level WM-190S 1-JAN-93

Option:

Appendix B
Regression Analyses

	Sump		Date:	7/23/93	14:16
Month	183 N	Recharge	Observation	Predicted Y	Residuals
Jan-89	0.00	0.15	1	0.781469807	-0.781469807
Feb-89	1.90	0.23	2	0.994932911	0.905067089
Mar-89	9.60	2.14	3	2.945757982	6.654242018
Apr-89	4.60	0.31	4	0.879091758	3.720908242
May-89	0.00	0.75	5	0.785604421	-0.785604421
Jun-89	0.00	1.21	6	0.803704213	-0.803704213
Jul-89	0.00	0.32	7	-0.096932448	0.096932448
Aug-89	0.00	0.41	8	-0.276733977	0.276733977
Sep-89	0.00	1.86	9	1.099477535	-1.099477535
Oct-89	0.00	0.29	10	-0.180803949	0.180803949
Nov-89	0.00	0.05	11	0.0895601	-0.0895601
Dec-89	0.00	0.14	12	0.451480912	-0.451480912
Jan-90	0.00	0.70	13	0.980361306	-0.980361306
Feb-90	0.00	0.80	14	1.244112173	-1.244112173
Mar-90	0.00	0.19	15	1.009685739	-1.009685739
Apr-90	0.00	0.97	16	1.238737913	-1.238737913
May-90	0.00	1.28	17	1.243633893	-1.243633893
Jun-90	0.00	0.86	18	0.495271875	-0.495271875
Jul-90	0.00	0.59	19	0.007666345	-0.007666345
Aug-90	0.00	0.68	20	-0.151445313	0.151445313
Sep-90	0.00	0.05	21	-0.372270479	0.372270479
Oct-90	0.00	0.25	22	-0.189999448	0.189999448
Nov-90	0.00	0.04	23	0.089230357	-0.089230357
Dec-90	0.00	0.07	24	0.444975253	-0.444975253
Jan-91	0.00	0.20	25	0.789023139	-0.789023139
Feb-91	0.00	0.15	26	0.981407845	-0.981407845
Mar-91	2.50	1.18	27	1.587086402	0.912913598
Apr-91	1.20	0.51	28	0.948909431	0.251090569
May-91	2.50	2.03	29	2.300477619	0.199522381
Jun-91	1.30	1.15	30	0.743422614	0.556577386
Jul-91	0.00	0.53	31	-0.020941872	0.020941872
Aug-91	0.00	0.78	32	-0.089290556	0.089290556
Sep-91	2.30	1.08	33	0.123222134	2.176777866
Oct-91	0.00	0.30	34	-0.178928131	0.178928131
Nov-91	0.00	0.57	35	0.227445173	-0.227445173
Dec-91	0.00	0.37	36	0.501794852	-0.501794852
Jan-92	0.00	0.01	37	0.771802296	-0.771802296
Feb-92	0.00	0.45	38	1.057860761	-1.057860761
Mar-92	0.00	0.28	39	1.025533616	-1.025533616
Apr-92	0.00	0.06	40	0.831860194	-0.831860194
May-92	0.00	0.31	41	0.575754991	-0.575754991
Jun-92	2.00	1.53	42	1.165220433	0.834779567
Jul-92	0.00	0.25	43	-0.12299721	0.12299721
Aug-92	0.00	0.07	44	-0.350052824	0.350052824
Sep-92	0.00	0.58	45	-0.227659961	0.227659961
Oct-92	0.00	0.33	46	-0.162315902	0.162315902
Nov-92	0.00	0.21	47	0.119319742	-0.119319742

Dec-92	0.00	0.10	48	0.459043924	-0.459043924
Jan-93	1.70	0.69	49	0.986002231	0.713997769
Feb-93	5.10	0.65	50	1.152593813	3.947406187
Mar-93	3.80	3.14	51	5.182259709	-1.382259709
Apr-93	0.00	1.20	52	1.44336083	-1.44336083
May-93	1.20	1.99	53	2.220727462	-1.020727462
Jun-93	2.00	2.73	54	3.34148836	-1.34148836
	Seepage	Recharge			
Min	0.00	0.01			
Max	9.60	3.14			
Median	0.00	0.41			
Average	0.75	0.59			
Total	39.70	26.74			

183 N

183 N

Regression Statistics						
Multiple R	0.5786342					
R Square	0.3348175					
Adjusted R Square	0.2949065					
Standard Error	1.4517834					
Observations	54					
Analysis of Variance						
	df	Sum of Squares	Mean Square	F	Significance F	
Regression	3	53.0445759	17.6815253	8.3891132	0.0001287	
Residual	50	105.383757	2.10767515			
Total	53	158.428333				
	Coefficients	Standard Error	t Statistic	P-value	Lower 95%	Upper 95%
Intercept	0.3088333	0.22457338	1.37520004	0.1748548	-0.142236	0.759902
Recharge ^ 2	0.4257175	0.11369322	3.74444059	0.0004469	0.1973579	0.654077
Sin(t)	0.6616572	0.28940319	2.28628161	0.0262622	0.0803735	1.242941
Cos(t)	0.215402	0.2923118	0.73689119	0.4644381	-0.371724	0.802528
Amplitude =	0.6958364	0.2908575	2.39236184	0.0102699	0.1124504	1.279222
Offset =	0.3147286	18.2830724	(days)			
	Max	Apr	Min	Jul

	Sump		Date:	7/26/93	9:33
Month	184 N	Recharge	Observation	Predicted Y	Residuals
Jan-89	0.00	0.15	1	0.063888393	-0.063888393
Feb-89	0.00	0.23	2	0.081551362	-0.081551362
Mar-89	0.60	2.14	3	0.367328677	0.232871323
Apr-89	0.00	0.31	4	0.060464413	-0.060464413
May-89	0.00	0.75	5	0.057367306	-0.057367306
Jun-89	0.00	1.21	6	0.077139443	-0.077139443
Jul-89	0.00	0.32	7	-0.039929216	0.039929216
Aug-89	0.00	0.41	8	-0.05225804	0.05225804
Sep-89	0.00	1.86	9	0.160482117	-0.160482117
Oct-89	0.00	0.29	10	-0.033735275	0.033735275
Nov-89	0.00	0.05	11	-0.004774195	0.004774195
Dec-89	0.00	0.14	12	0.032745095	-0.032745095
Jan-90	0.00	0.70	13	0.093651437	-0.093651437
Feb-90	0.00	0.80	14	0.118839699	-0.118839699
Mar-90	0.00	0.19	15	0.077605873	-0.077605873
Apr-90	0.00	0.97	16	0.114283527	-0.114283527
May-90	0.00	1.28	17	0.125908955	-0.125908955
Jun-90	0.00	0.86	18	0.030984201	-0.030984201
Jul-90	0.00	0.59	19	-0.024276569	0.024276569
Aug-90	0.00	0.68	20	-0.033509265	0.033509265
Sep-90	0.00	0.05	21	-0.059757062	0.059757062
Oct-90	0.00	0.25	22	-0.035111332	0.035111332
Nov-90	0.00	0.04	23	-0.00482354	0.00482354
Dec-90	0.00	0.07	24	0.031771559	-0.031771559
Jan-91	0.00	0.20	25	0.065018709	-0.065018709
Feb-91	0.00	0.15	26	0.079527408	-0.079527408
Mar-91	0.60	1.18	27	0.164010779	0.435989221
Apr-91	0.20	0.51	28	0.070912252	0.129087748
May-91	0.20	2.03	29	0.284059937	-0.084059937
Jun-91	0.00	1.15	30	0.068118625	-0.068118625
Jul-91	0.00	0.53	31	-0.028557634	0.028557634
Aug-91	0.00	0.78	32	-0.024208139	0.024208139
Sep-91	0.00	1.08	33	0.014390744	-0.014390744
Oct-91	0.00	0.30	34	-0.033454569	0.033454569
Nov-91	0.00	0.57	35	0.015859565	-0.015859565
Dec-91	0.00	0.37	36	0.040274306	-0.040274306
Jan-92	0.00	0.01	37	0.062441702	-0.062441702
Feb-92	0.30	0.45	38	0.090968176	0.209031824
Mar-92	0.00	0.28	39	0.079900719	-0.079900719
Apr-92	0.00	0.06	40	0.053634299	-0.053634299
May-92	0.00	0.31	41	0.026444516	-0.026444516
Jun-92	0.00	1.53	42	0.131836732	-0.131836732
Jul-92	0.00	0.25	43	-0.043275302	0.043275302
Aug-92	0.00	0.07	44	-0.062872293	0.062872293
Sep-92	0.00	0.58	45	-0.038055621	0.038055621
Oct-92	0.00	0.33	46	-0.031211228	0.031211228
Nov-92	0.00	0.21	47	-0.000810105	0.000810105

Dec-92	0.00	0.10	48	0.033277958	-0.033277958
Jan-93	0.00	0.69	49	0.09394747	-0.09394747
Feb-93	0.50	0.65	50	0.104799583	0.395200417
Mar-93	0.60	3.14	51	0.701932435	-0.101932435
Apr-93	0.00	1.20	52	0.145142082	-0.145142082
May-93	0.50	1.99	53	0.272605803	0.227394197
Jun-93	0.50	2.73	54	0.457503528	0.042496472
	Seepage	Recharge		Predicted	Residual
Min	0.00	0.01		-0.06	-0.16
Max	0.60	3.14		0.70	0.44
Median	0.00	0.41		0.05	-0.03
Average	0.07	0.59		0.05	-0.01
Total	4.00	37.78		4.00	0.00

Regression Statistics						
Multiple R	0.7504197					
R Square	0.5631297					
Adjusted R Square	0.5369175					
Standard Error	0.122008					
Observations	54					
Analysis of Variance						
	df	Sum of Squares	Mean Square	F	Significance F	
Regression	3	0.95940619	0.31980206	21.483483	4.45E-09	
Residual	50	0.74429752	0.01488595			
Total	53	1.7037037				
	Coefficients	Standard Error	t Statistic	P-value	Lower 95%	Upper 95%
Intercept	0.0073912	0.01887316	0.39162323	0.6969068	-0.030517	0.045299
Recharge^2	0.0637063	0.00955479	6.66747843	1.546E-08	0.044515	0.082898
Sin(t)	0.0640254	0.02432147	2.63246411	0.011081	0.0151743	0.112877
Cos(t)	0.0320339	0.02456591	1.30399973	0.1978689	-0.017308	0.081376
Amplitude =	0.0715921	0.02444369	2.92885697	0.0025562	0.0225643	0.12062
Offset =	0.463913	26.9494264	(days)			
	Max	Apr	Min	Oct		

184 N

	Sump		Date:	7/26/93	9:39
Month	185 S	Recharge	Observation	Predicted Y	Residuals
Jan-89	0.00	0.15	1	0.176172328	-0.176172328
Feb-89	0.00	0.23	2	0.231260645	-0.231260645
Mar-89	2.90	2.14	3	2.229124717	0.670875283
Apr-89	0.40	0.31	4	0.186272132	0.213727868
May-89	0.25	0.75	5	0.305936203	-0.055936203
Jun-89	0.25	1.21	6	0.605653307	-0.355653307
Jul-89	0.20	0.32	7	-0.077215365	0.277215365
Aug-89	0.20	0.41	8	-0.09143289	0.29143289
Sep-89	0.20	1.86	9	1.374440848	-1.174440848
Oct-89	0.20	0.29	10	-0.064885771	0.264885771
Nov-89	0.00	0.05	11	-0.01059764	0.01059764
Dec-89	0.00	0.14	12	0.093207403	-0.093207403
Jan-90	0.00	0.70	13	0.383040564	-0.383040564
Feb-90	0.00	0.80	14	0.490433483	-0.490433483
Mar-90	1.70	0.19	15	0.215404419	1.484595581
Apr-90	0.00	0.97	16	0.560342245	-0.560342245
May-90	0.00	1.28	17	0.782335391	-0.782335391
Jun-90	0.00	0.86	18	0.284850991	-0.284850991
Jul-90	0.40	0.59	19	0.031578464	0.368421536
Aug-90	0.30	0.68	20	0.038880598	0.261119402
Sep-90	0.30	0.05	21	-0.156333048	0.456333048
Oct-90	0.20	0.25	22	-0.074450063	0.274450063
Nov-90	0.00	0.04	23	-0.010940607	0.010940607
Dec-90	0.00	0.07	24	0.086440829	-0.086440829
Jan-91	0.00	0.20	25	0.184028594	-0.184028594
Feb-91	0.00	0.15	26	0.217193143	-0.217193143
Mar-91	0.60	1.18	27	0.815962296	-0.215962296
Apr-91	0.20	0.51	28	0.25888991	-0.05888991
May-91	1.30	2.03	29	1.88156486	-0.58156486
Jun-91	0.60	1.15	30	0.542954055	0.057045945
Jul-91	0.15	0.53	31	0.001822887	0.148177113
Aug-91	0.15	0.78	32	0.103528131	0.046471869
Sep-91	0.15	1.08	33	0.359031778	-0.209031778
Oct-91	0.15	0.30	34	-0.062934721	0.212934721
Nov-91	0.00	0.57	35	0.132817449	-0.132817449
Dec-91	0.00	0.37	36	0.145539233	-0.145539233
Jan-92	0.00	0.01	37	0.166117093	-0.166117093
Feb-92	0.20	0.45	38	0.296712277	-0.096712277
Mar-92	0.30	0.28	39	0.233066402	0.066933598
Apr-92	0.10	0.06	40	0.14282949	-0.04282949
May-92	0.00	0.31	41	0.096218321	-0.096218321
Jun-92	0.80	1.53	42	0.990830417	-0.190830417
Jul-92	0.30	0.25	43	-0.09699874	0.39699874
Aug-92	0.25	0.07	44	-0.164259085	0.414259085
Sep-92	0.20	0.58	45	-0.007337862	0.207337862
Oct-92	0.10	0.33	46	-0.051402073	0.151402073
Nov-92	0.00	0.21	47	0.011719132	-0.011719132

Dec-92	0.00	0.10	48	0.091923307	-0.091923307
Jan-93	0.00	0.69	49	0.381729345	-0.381729345
Feb-93	0.60	0.65	50	0.392034512	0.207965488
Mar-93	6.00	3.14	51	4.556502028	1.443497972
Apr-93	1.50	1.20	52	0.778854951	0.721145049
May-93	1.70	1.99	53	1.807164008	-0.107164008
Jun-93	2.20	2.73	54	3.254379679	-1.054379679
	Seepage	Recharge		Predicted	Residual
Min	0.00	0.01		-0.16	-1.17
Max	6.00	3.14		4.56	1.48
Median	0.20	0.41		0.18	-0.06
Average	0.43	0.59		0.31	-0.02
Total	25.05	37.78		25.05	0.00

185 S

185 S

Regression Statistics						
Multiple R	0.8789413					
R Square	0.7725377					
Adjusted R Square	0.75889					
Standard Error	0.4786776					
Observations	54					
Analysis of Variance						
	df	Sum of Squares	Mean Square	F	Significance F	
Regression	3	38.910472	12.9701573	56.605557	4.236E-16	
Residual	50	11.4566114	0.22913223			
Total	53	50.3670833				
	Coefficients	Standard Error	t Statistic	P-value	Lower 95%	Upper 95%
Intercept	0.0201788	0.07404564	0.27251888	0.786282	-0.128546	0.168904
Recharge^2	0.4427913	0.03748658	11.8119958	1.816E-16	0.3674973	0.518085
Sin(t)	0.1688721	0.09542113	1.76975563	0.0825204	-0.022787	0.360531
Cos(t)	0.0852679	0.09638015	0.88470438	0.3803122	-0.108317	0.278853
Amplitude =	0.1891782	0.09590064	1.97264824	0.027039	-0.003174	0.38153
Offset =	0.4675808	27.1624954	(days)			
	Max	Apr	Min	Oct

	Sump		Date:	7/26/93	9:49
Month	186 S	Recharge	Observation	Predicted Y	Residuals
Jan-89	0.00	0.15	1	0.203726858	-0.203726858
Feb-89	0.00	0.23	2	0.312087608	-0.312087608
Mar-89	2.50	2.14	3	1.451521195	1.048478805
Apr-89	0.00	0.31	4	0.371012733	-0.371012733
May-89	0.00	0.75	5	0.423172896	-0.423172896
Jun-89	0.00	1.21	6	0.534860515	-0.534860515
Jul-89	0.00	0.32	7	0.09163276	-0.09163276
Aug-89	0.00	0.41	8	0.005076442	-0.005076442
Sep-89	0.00	1.86	9	0.739598692	-0.739598692
Oct-89	0.00	0.29	10	-0.067499	0.067499
Nov-89	0.00	0.05	11	-0.023484798	0.023484798
Dec-89	0.00	0.14	12	0.083229005	-0.083229005
Jan-90	0.00	0.70	13	0.31599227	-0.31599227
Feb-90	0.00	0.80	14	0.452738227	-0.452738227
Mar-90	0.00	0.19	15	0.358694454	-0.358694454
Apr-90	0.00	0.97	16	0.574017004	-0.574017004
May-90	0.00	1.28	17	0.681710178	-0.681710178
Jun-90	0.00	0.86	18	0.360764167	-0.360764167
Jul-90	0.00	0.59	19	0.15067413	-0.15067413
Aug-90	0.00	0.68	20	0.075796325	-0.075796325
Sep-90	0.00	0.05	21	-0.091137657	-0.091137657
Oct-90	0.00	0.25	22	-0.07268945	0.07268945
Nov-90	0.00	0.04	23	-0.023670923	0.023670923
Dec-90	0.00	0.07	24	0.07955685	-0.07955685
Jan-91	0.00	0.20	25	0.207990378	-0.207990378
Feb-91	0.00	0.15	26	0.304453309	-0.304453309
Mar-91	1.80	1.18	27	0.684611468	1.115388532
Apr-91	1.20	0.51	28	0.410421706	0.789578294
May-91	1.00	2.03	29	1.278251494	-0.278251494
Jun-91	1.80	1.15	30	0.500834231	1.299165769
Jul-91	0.40	0.53	31	0.134526063	0.265473937
Aug-91	0.10	0.78	32	0.110879923	-0.010879923
Sep-91	0.10	1.08	33	0.188545903	-0.088545903
Oct-91	0.10	0.30	34	-0.066440184	0.166440184
Nov-91	0.00	0.57	35	0.054345199	-0.054345199
Dec-91	0.00	0.37	36	0.111628989	-0.111628989
Jan-92	0.00	0.01	37	0.198269978	-0.198269978
Feb-92	1.50	0.45	38	0.347607582	1.152392418
Mar-92	0.00	0.28	39	0.369791427	-0.369791427
Apr-92	0.00	0.06	40	0.347655608	-0.347655608
May-92	0.00	0.31	41	0.308266397	-0.308266397
Jun-92	1.10	1.53	42	0.741744072	0.358255928
Jul-92	0.40	0.25	43	0.07829536	0.32170464
Aug-92	0.00	0.07	44	-0.03680211	0.03680211
Sep-92	0.00	0.58	45	-0.011735907	0.011735907
Oct-92	0.00	0.33	46	-0.060377904	0.060377904
Nov-92	0.00	0.21	47	-0.010218242	0.010218242

Dec-92	0.00	0.10	48	0.084693211	-0.084693211
Jan-93	0.90	0.69	49	0.317886906	0.582113094
Feb-93	1.50	0.65	50	0.401664685	1.098335315
Mar-93	1.80	3.14	51	2.716078579	-0.916078579
Apr-93	0.00	1.20	52	0.692820542	-0.692820542
May-93	1.70	1.99	53	1.236780252	0.463219748
Jun-93	2.70	2.73	54	1.970150602	0.729849398
Seepage		Recharge		Predicted	Residual
Min	0.00	0.01		-0.09	-0.92
Max	2.50	3.14		2.72	1.30
Median	0.00	0.41		0.21	-0.09
Average	0.34	0.59		0.29	-0.03
Total	20.60	37.78		20.60	0.00

Regression Statistics						
Multiple R	0.7202883					
R Square	0.5188153					
Adjusted R Square	0.4899442					
Standard Error	0.5153913					
Observations	54					
Analysis of Variance						
	<i>df</i>	<i>Sum of Squares</i>	<i>Mean Square</i>	<i>F</i>	<i>Significance F</i>	
Regression	3	14.320071	4.773357	17.970068	4.794E-08	
Residual	50	13.2814105	0.26562821			
Total	53	27.6014815				
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Statistic</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>
Intercept	0.1298276	0.07972482	1.6284467	0.1093608	-0.030304	0.28996
Recharge^2	0.2402986	0.04036174	5.95362449	2.146E-07	0.1592297	0.321368
Sin(t)	0.2259099	0.10273977	2.19885546	0.0322744	0.0195509	0.432269
Cos(t)	-0.024329	0.10377234	-0.2344429	0.8155445	-0.232762	0.184104
Amplitude =	0.2272161	0.10325605	2.20051141	0.0162089	0.0201108	0.434321
Offset =	-0.107279	-6.23197769	(days)			
	Max	Mar	Min	Sep		

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	Sump		Date:	7/26/93	9:55
Month	187 S	Recharge	Observation	Predicted Y	Residuals
Jan-89	0.90	0.15	1	0.541639768	0.358360232
Feb-89	0.90	0.23	2	0.676806001	0.223193999
Mar-89	4.80	2.14	3	3.51738317	1.28261683
Apr-89	0.90	0.31	4	0.570550331	0.329449669
May-89	0.20	0.75	5	0.653877141	-0.453877141
Jun-89	0.20	1.21	6	0.972050167	-0.772050167
Jul-89	0.20	0.32	7	-0.090350757	0.290350757
Aug-89	0.30	0.41	8	-0.16984112	0.46984112
Sep-89	0.00	1.86	9	1.905204798	-1.905204798
Oct-89	0.10	0.29	10	-0.090173233	0.190173233
Nov-89	0.00	0.05	11	0.077223906	-0.077223906
Dec-89	0.00	0.14	12	0.328496056	-0.328496056
Jan-90	0.00	0.70	13	0.835251488	-0.835251488
Feb-90	0.70	0.80	14	1.044654561	-0.344654561
Mar-90	2.00	0.19	15	0.659274589	1.340725411
Apr-90	0.30	0.97	16	1.101474611	-0.801474611
May-90	0.00	1.28	17	1.330038875	-1.330038875
Jun-90	0.00	0.86	18	0.516729806	-0.516729806
Jul-90	0.60	0.59	19	0.064062235	0.535937765
Aug-90	0.30	0.68	20	0.015115101	0.284884899
Sep-90	0.40	0.05	21	-0.267449474	0.667449474
Oct-90	0.10	0.25	22	-0.103748001	0.203748001
Nov-90	0.00	0.04	23	0.076737127	-0.076737127
Dec-90	0.00	0.07	24	0.318892138	-0.318892138
Jan-91	0.00	0.20	25	0.552790305	-0.552790305
Feb-91	1.20	0.15	26	0.656839749	0.543160251
Mar-91	1.20	1.18	27	1.511656929	-0.311656929
Apr-91	1.00	0.51	28	0.673618018	0.326381982
May-91	1.50	2.03	29	2.890194563	-1.390194563
Jun-91	1.20	1.15	30	0.883060017	0.316939983
Jul-91	0.50	0.53	31	0.021829622	0.478170378
Aug-91	0.60	0.78	32	0.106870481	0.493129519
Sep-91	0.40	1.08	33	0.464016873	-0.064016873
Oct-91	0.10	0.30	34	-0.087404074	0.187404074
Nov-91	0.10	0.57	35	0.280775459	-0.180775459
Dec-91	0.10	0.37	36	0.402771541	-0.302771541
Jan-92	0.00	0.01	37	0.527368197	-0.527368197
Feb-92	0.70	0.45	38	0.769702652	-0.069702652
Mar-92	0.30	0.28	39	0.683651111	-0.383651111
Apr-92	0.30	0.06	40	0.50654709	-0.20654709
May-92	0.20	0.31	41	0.352894174	-0.152894174
Jun-92	0.80	1.53	42	1.515309579	-0.715309579
Jul-92	0.80	0.25	43	-0.121048359	0.921048359
Aug-92	0.20	0.07	44	-0.27427245	0.47427245
Sep-92	0.30	0.58	45	-0.055198006	0.355198006
Oct-92	0.00	0.33	46	-0.068668881	0.068668881
Nov-92	0.10	0.21	47	0.112252759	-0.012252759

Dec-92	0.10	0.10	48	0.33009628	-0.23009628
Jan-93	1.00	0.69	49	0.835948052	0.164051948
Feb-93	1.50	0.65	50	0.905976397	0.594023603
Mar-93	8.20	3.14	51	6.819979216	1.380020784
Apr-93	2.00	1.20	52	1.409269196	0.590730804
May-93	3.00	1.99	53	2.781269432	0.218730568
Jun-93	4.30	2.73	54	4.728004796	-0.428004796
	Seepage	Recharge		Predicted	Residual
Min	0.00	0.01		-0.27	-1.91
Max	8.20	3.14		6.82	1.38
Median	0.30	0.41		0.52	-0.07
Average	0.76	0.59		0.59	-0.05
Total	44.60	37.78		44.60	0.00

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187 S

Regression Statistics						
Multiple R	0.8924969					
R Square	0.7965507					
Adjusted R Square	0.7843437					
Standard Error	0.6584261					
Observations	54					
Analysis of Variance						
	df	Sum of Squares	Mean Square	F	Significance F	
Regression	3	84.8674578	28.2891526	65.25381	2.642E-17	
Residual	50	21.6762459	0.43352492			
Total	53	106.543704				
	Coefficients	Standard Error	t Statistic	P-value	Lower 95%	Upper 95%
Intercept	0.1821026	0.10185057	1.78793847	0.0795033	-0.02247	0.386676
Recharge^2	0.6284615	0.05156319	12.1881816	5.349E-17	0.5248938	0.732029
Sin(t)	0.432312	0.13125278	3.29373559	0.0017655	0.1686829	0.695941
Cos(t)	0.1874019	0.13257192	1.41358696	0.1633301	-0.078877	0.453681
Amplitude =	0.4711827	0.13191235	3.57193752	0.0003975	0.2066001	0.735765
Offset =	0.4090378	23.7616432	(days)			
	Max	Apr	Min	Oct		

187 S

	Sump		Date:	7/26/93	10:02
Month	188 N	Recharge	Observation	Predicted Y	Residuals
Jan-89	0.50	0.15	1	0.525644803	-0.025644803
Feb-89	1.00	0.23	2	0.644827109	0.355172891
Mar-89	5.00	2.14	3	3.205086619	1.794913381
Apr-89	0.70	0.31	4	0.548364791	0.151635209
May-89	0.20	0.75	5	0.625606169	-0.425606169
Jun-89	0.20	1.21	6	0.915775312	-0.715775312
Jul-89	0.20	0.32	7	-0.03884096	0.23884096
Aug-89	0.20	0.41	8	-0.10776196	0.30776196
Sep-89	0.20	1.86	9	1.784608837	-1.584608837
Oct-89	0.20	0.29	10	-0.035197116	0.235197116
Nov-89	0.10	0.05	11	0.113528264	-0.013528264
Dec-89	0.00	0.14	12	0.336920338	-0.336920338
Jan-90	0.00	0.70	13	0.790400064	-0.790400064
Feb-90	0.80	0.80	14	0.976523137	-0.176523137
Mar-90	2.00	0.19	15	0.627875865	1.372124135
Apr-90	0.20	0.97	16	1.027109292	-0.827109292
May-90	0.20	1.28	17	1.235314038	-1.035314038
Jun-90	0.20	0.86	18	0.505204301	-0.305204301
Jul-90	0.25	0.59	19	0.100396166	0.149603834
Aug-90	0.25	0.68	20	0.059016575	0.190983425
Sep-90	0.10	0.05	21	-0.194514756	0.294514756
Oct-90	0.25	0.25	22	-0.047437742	0.297437742
Nov-90	0.10	0.04	23	0.113089327	-0.013089327
Dec-90	0.00	0.07	24	0.328260303	-0.328260303
Jan-91	0.00	0.20	25	0.535699454	-0.535699454
Feb-91	0.00	0.15	26	0.62682316	-0.62682316
Mar-91	1.20	1.18	27	1.396485199	-0.196485199
Apr-91	1.20	0.51	28	0.641302881	0.558697119
May-91	1.90	2.03	29	2.642136033	-0.742136033
Jun-91	1.20	1.15	30	0.835531206	0.364468794
Jul-91	0.60	0.53	31	0.062314217	0.537685783
Aug-91	0.60	0.78	32	0.141754142	0.458245858
Sep-91	0.50	1.08	33	0.465062331	0.034937669
Oct-91	0.50	0.30	34	-0.032700113	0.532700113
Nov-91	0.25	0.57	35	0.297074564	-0.047074564
Dec-91	0.50	0.37	36	0.403895953	0.096104047
Jan-92	0.20	0.01	37	0.512775856	-0.312775856
Feb-92	1.00	0.45	38	0.728593783	0.271406217
Mar-92	0.75	0.28	39	0.649843176	0.100156824
Apr-92	0.25	0.06	40	0.490698267	-0.240698267
May-92	0.25	0.31	41	0.354296334	-0.104296334
Jun-92	0.50	1.53	42	1.40575683	-0.90575683
Jul-92	0.50	0.25	43	-0.066416348	0.566416348
Aug-92	0.40	0.07	44	-0.20186246	0.60186246
Sep-92	0.10	0.58	45	-0.003113066	0.103113066
Oct-92	0.10	0.33	46	-0.01585355	0.11585355
Nov-92	0.00	0.21	47	0.145020492	-0.145020492

Dec-92	0.00	0.10	48	0.338248997	-0.338248997
Jan-93	1.00	0.69	49	0.790924168	0.209075832
Feb-93	0.80	0.65	50	0.851409618	-0.051409618
Mar-93	7.00	3.14	51	6.183086694	0.816913306
Apr-93	1.70	1.20	52	1.304699925	0.395300075
May-93	2.70	1.99	53	2.544008394	0.155991606
Jun-93	3.80	2.73	54	4.302705084	-0.502705084
	Seepage	Recharge		Predicted	Residual
Min	0.00	0.01		-0.20	-1.56
Max	7.00	3.14		6.18	1.79
Median	0.25	0.41		0.51	0.03
Average	0.73	0.59		0.58	-0.01
Total	42.35	37.78		42.35	0.00

Regression Statistics						
Multiple R	0.8946956					
R Square	0.8004802					
Adjusted R Square	0.788509					
Standard Error	0.5853817					
Observations	54					
Analysis of Variance		df	Sum of Squares	Mean Square	F	Significance F
Regression		3	68.7405357	22.9135119	66.867244	1.626E-17
Residual		50	17.1335847	0.34267169		
Total		53	85.8741204			
	Coefficients	Standard Error	t Statistic	P-value	Lower 95%	Upper 95%
Intercept	0.2042181	0.09055148	2.25527054	0.0282703	0.02234	0.386096
Recharge^2	0.5666957	0.04584288	12.3616955	3.063E-17	0.4746175	0.658774
Sin(t)	0.3831545	0.11669187	3.28347178	0.0018197	0.1487718	0.617537
Cos(t)	0.1688779	0.11786467	1.43281151	0.1577842	-0.06786	0.405616
Amplitude =	0.4187208	0.11727827	3.57031835	0.0003995	0.1834904	0.653951
Offset =	0.4151406	24.1161607	(days)			
	Max	Apr	Min	Oct		

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	Sump		Date:	7/26/93	11:29
Month	189 C	Recharge	Observation	Predicted Y	Residuals
Jan-89	78.40	0.15	1	18.39213855	60.00786145
Feb-89	81.20	0.23	2	23.64293996	57.55706004
Mar-89	182.00	2.14	3	60.53420236	121.4657976
Apr-89	61.60	0.31	4	26.67560435	34.92439565
May-89	79.50	0.75	5	27.4347016	52.0652984
Jun-89	89.60	1.21	6	29.2246572	60.3753428
Jul-89	51.00	0.32	7	13.26603603	37.73396397
Aug-89	15.80	0.41	8	8.677126883	7.122873117
Sep-89	8.80	1.86	9	30.65682838	-21.85682838
Oct-89	13.20	0.29	10	5.146253857	8.053746143
Nov-89	0.00	0.05	11	7.474801628	-7.474801628
Dec-89	30.80	0.14	12	12.52327838	18.27672162
Jan-90	58.80	0.70	13	21.92545634	36.87454366
Feb-90	63.80	0.80	14	28.06962245	35.73037755
Mar-90	0.00	0.19	15	26.1397787	-26.1397787
Apr-90	0.00	0.97	16	33.06473692	-33.06473692
May-90	0.00	1.28	17	35.5716189	-35.5716189
Jun-90	0.00	0.86	18	23.74534074	-23.74534074
Jul-90	0.00	0.59	19	15.124239	-15.124239
Aug-90	0.00	0.68	20	10.90288649	-10.90288649
Sep-90	0.00	0.05	21	4.511148698	-4.511148698
Oct-90	0.00	0.25	22	4.982895354	-4.982895354
Nov-90	0.00	0.04	23	7.468943742	-7.468943742
Dec-90	7.80	0.07	24	12.40770502	-4.607705017
Jan-91	8.00	0.20	25	18.52632389	-10.52632389
Feb-91	36.00	0.15	26	23.40266646	12.59733354
Mar-91	0.00	1.18	27	36.39733138	-36.39733138
Apr-91	0.00	0.51	28	27.91591891	-27.91591891
May-91	0.00	2.03	29	54.34650242	-54.34650242
Jun-91	0.00	1.15	30	28.15375146	-28.15375146
Jul-91	0.00	0.53	31	14.61601255	-14.61601255
Aug-91	0.00	0.78	32	12.00706896	-12.00706896
Sep-91	0.00	1.08	33	13.31360063	-13.31360063
Oct-91	6.40	0.30	34	5.179577857	1.220422143
Nov-91	8.00	0.57	35	9.924337106	-1.924337106
Dec-91	0.00	0.37	36	13.41710814	-13.41710814
Jan-92	3.00	0.01	37	18.22039473	-15.22039473
Feb-92	0.00	0.45	38	24.76085647	-24.76085647
Mar-92	0.00	0.28	39	26.51099386	-26.51099386
Apr-92	9.00	0.06	40	25.92673133	-16.92673133
May-92	0.00	0.31	41	23.77348325	-23.77348325
Jun-92	0.00	1.53	42	35.67138868	-35.67138868
Jul-92	93.00	0.25	43	12.77975293	80.22024707
Aug-92	0.00	0.07	44	7.308671472	-7.308671472
Sep-92	0.00	0.58	45	6.989855805	-6.989855805
Oct-92	0.00	0.33	46	5.384703532	-5.384703532
Nov-92	0.00	0.21	47	7.938418249	-7.938418249

Dec-92	0.00	0.10	48	12.63403409	-12.63403409
Jan-93	6.00	0.69	49	22.05123253	-16.05123253
Feb-93	6.00	0.65	50	26.51141635	-20.51141635
Mar-93	30.00	3.14	51	100.3554482	-70.35544817
Apr-93	24.00	1.20	52	36.79007179	-12.79007179
May-93	57.00	1.99	53	52.99650437	4.003495627
Jun-93	157.00	2.73	54	74.33290109	82.66709891
	Seepage	Recharge		Predicted	Residual
Min	0.00	0.01		4.51	-70.36
Max	182.00	3.14		100.36	121.47
Median	0.00	0.41		18.53	-7.47
Average	20.92	0.59		20.59	1.31
Total	1265.70	37.78		1265.70	0.00

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Regression Statistics						
Multiple R	0.4498037					
R Square	0.2023233					
Adjusted R Square	0.1544627					
Standard Error	36.960806					
Observations	54					
Analysis of Variance						
	df	Sum of Squares	Mean Square	F	Significance F	
Regression	3	17324.9484	5774.9828	4.2273463	0.0096919	
Residual	50	68305.0599	1366.1012			
Total	53	85630.0083				
	Coefficients	Standard Error	t Statistic	P-value	Lower 95%	Upper 95%
Intercept	15.217384	5.71739062	2.66159606	0.0102712	3.7336626	26.70111
Recharge^2	7.5628937	2.89450411	2.61284606	0.0116587	1.7491087	13.37668
Sin(t)	10.976999	7.36788633	1.48984369	0.1421927	-3.821842	25.77584
Cos(t)	-1.533938	7.44193636	-0.2061208	0.8374863	-16.48151	13.41364
Amplitude =	11.083658	7.40491134	1.49679819	0.0703661	-3.768706	25.93602
Offset =	-0.138842	-8.06554918	(days)			
	Max	Mar	Min	Sep

	Sump		Date:	7/26/93	9:13
Month	189 S	Recharge	Observation	Predicted Y	Residuals
Jan-89	1.90	0.15	1	5.098217163	-3.198217163
Feb-89	5.60	0.23	2	5.914873462	-0.314873462
Mar-89	22.40	2.14	3	18.08024723	4.319752766
Apr-89	5.90	0.31	4	6.168149423	-0.268149423
May-89	2.00	0.75	5	6.794920012	-4.794920012
Jun-89	1.40	1.21	6	8.248309984	-6.848309984
Jul-89	7.90	0.32	7	3.753024704	4.146975296
Aug-89	4.00	0.41	8	3.175801894	0.824198106
Sep-89	0.70	1.86	9	11.46808183	-10.76808183
Oct-89	3.30	0.29	10	2.790673264	0.509326736
Nov-89	1.60	0.05	11	3.204244539	-1.604244539
Dec-89	0.60	0.14	12	4.134642221	-3.534642221
Jan-90	5.30	0.70	13	6.322185575	-1.022185575
Feb-90	7.00	0.80	14	7.448310266	-0.448310266
Mar-90	10.60	0.19	15	6.165754781	4.434245219
Apr-90	4.40	0.97	16	8.381394004	-3.981394004
May-90	1.80	1.28	17	9.613610642	-7.813610642
Jun-90	8.80	0.86	18	6.350232689	2.449767311
Jul-90	3.10	0.59	19	4.396720482	-1.296720482
Aug-90	2.25	0.68	20	3.946822112	-1.696822112
Sep-90	1.10	0.05	21	2.411017626	-1.311017626
Oct-90	11.20	0.25	22	2.734084624	8.465915376
Nov-90	17.90	0.04	23	3.202215322	14.69778468
Dec-90	6.70	0.07	24	4.094606721	2.605393279
Jan-91	1.40	0.20	25	5.144699997	-3.744699997
Feb-91	2.30	0.15	26	5.831640876	-3.531640876
Mar-91	13.20	1.18	27	9.719049792	3.480950208
Apr-91	11.20	0.51	28	6.597803911	4.602196089
May-91	19.60	2.03	29	16.11737446	3.482625543
Jun-91	11.20	1.15	30	7.877340012	3.322659988
Jul-91	7.60	0.53	31	4.220666936	3.379333064
Aug-91	3.00	0.78	32	4.3293194	-1.3293194
Sep-91	4.60	1.08	33	5.460254567	-0.860254567
Oct-91	2.40	0.30	34	2.802216953	-0.402216953
Nov-91	8.50	0.57	35	4.052782438	4.447217562
Dec-91	7.60	0.37	36	4.444271712	3.155728288
Jan-92	7.00	0.01	37	5.038723786	1.961276214
Feb-92	6.00	0.45	38	6.302128325	-0.302128325
Mar-92	4.50	0.28	39	6.279680189	-1.779680189
Apr-92	6.75	0.06	40	5.912439928	0.837560072
May-92	6.50	0.31	41	5.547202525	0.952797475
Jun-92	8.00	1.53	42	10.5138032	-2.513803196
Jul-92	5.30	0.25	43	3.619693305	1.680306695
Aug-92	2.70	0.07	44	2.730187869	-0.030187869
Sep-92	1.80	0.58	45	3.283493275	-1.483493275
Oct-92	0.70	0.33	46	2.86926618	-2.16926618
Nov-92	0.70	0.21	47	3.34355417	-2.64355417

Dec-92	0.40	0.10	48	4.140591465	-3.740591465
Jan-93	1.30	0.69	49	6.330738102	-5.030738102
Feb-93	2.70	0.65	50	6.880656014	-4.180656014
Mar-93	33.10	3.14	51	31.85996618	1.240033822
Apr-93	12.90	1.20	52	9.675584478	3.224415522
May-93	21.00	1.99	53	15.67028143	5.32971857
Jun-93	23.00	2.73	54	23.90644796	-0.90644796
	Seepage	Recharge		Predicted	Residual
Min	0.40	0.01		2.41	-10.77
Max	33.10	3.14		31.86	14.70
Median	5.30	0.41		5.46	-0.30
Average	6.63	0.59		5.99	0.20
Total	374.40	37.78		374.40	0.00

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Regression Statistics						
Multiple R	0.7928994					
R Square	0.6286895					
Adjusted R Square	0.6064109					
Standard Error	4.2641834					
Observations	54					
Analysis of Variance						
	df	Sum of Squares	Mean Square	F	Significance F	
Regression	3	1539.36201	513.120671	28.219399	8.042E-11	
Residual	50	909.162987	18.1832597			
Total	53	2448.525				
	Coefficients	Standard Error	t Statistic	P-value	Lower 95%	Upper 95%
Intercept	4.2400508	0.6596177	6.42804282	3.747E-08	2.9151691	5.564932
Recharge^2	2.6198444	0.33394013	7.84525201	1.978E-10	1.9491057	3.290583
Sin(t)	1.8404631	0.85003606	2.16515889	0.0348976	0.1331148	3.547812
Cos(t)	0.0649519	0.85857925	0.07565046	0.939982	-1.659556	1.78946
Amplitude =	1.8416089	0.85430766	2.15567411	0.0179735	0.1280855	3.555132
Offset =	0.0352764	2.04926277	(days)			
	Max	Apr	Min	Oct		

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	Sump		Date:	7/26/93	10:30
Month	190 C	Recharge	Observation	Predicted Y	Residuals
Jan-89	5.60	0.15	1	12.71762084	-7.117620844
Feb-89	22.40	0.23	2	17.04973402	5.350265981
Mar-89	131.60	2.14	3	58.27852434	73.32147566
Apr-89	40.30	0.31	4	25.49275289	14.80724711
May-89	50.40	0.75	5	31.48387805	18.91612195
Jun-89	23.50	1.21	6	38.79818202	-15.29818202
Jul-89	27.00	0.32	7	25.36811269	1.631887305
Aug-89	15.00	0.41	8	21.89086839	-6.890868395
Sep-89	12.00	1.86	9	44.24429871	-32.24429871
Oct-89	13.80	0.29	10	12.82833938	0.971660624
Nov-89	15.60	0.05	11	9.985571665	5.614428335
Dec-89	9.00	0.14	12	10.26583821	-1.265838206
Jan-90	12.60	0.70	13	16.54186871	-3.941868714
Feb-90	15.10	0.80	14	21.8409054	-6.740905404
Mar-90	25.20	0.19	15	21.05209601	4.147903992
Apr-90	20.20	0.97	16	32.40796065	-12.20796065
May-90	33.60	1.28	17	40.2907815	-6.690781499
Jun-90	46.20	0.86	18	32.86770376	13.33229624
Jul-90	18.20	0.59	19	27.37931836	-9.179318363
Aug-90	21.60	0.68	20	24.29989496	-2.699894964
Sep-90	20.20	0.05	21	15.94580821	4.254191785
Oct-90	16.80	0.25	22	12.65153009	4.148469913
Nov-90	16.80	0.04	23	9.979231445	6.820768555
Dec-90	17.30	0.07	24	10.14074864	7.15925136
Jan-91	24.00	0.20	25	12.86285488	11.13714512
Feb-91	17.60	0.15	26	16.78967662	0.810323378
Mar-91	44.00	1.18	27	32.15424598	11.84575402
Apr-91	32.00	0.51	28	26.83519379	5.164806211
May-91	60.00	2.03	29	60.61157137	-0.611571371
Jun-91	44.00	1.15	30	37.6390989	6.360901104
Jul-91	33.80	0.53	31	26.82924502	6.970754982
Aug-91	36.40	0.78	32	25.49499479	10.90500521
Sep-91	17.70	1.08	33	25.47304581	-7.773045811
Oct-91	20.80	0.30	34	12.86440724	7.935592756
Nov-91	19.50	0.57	35	12.6367996	6.863200397
Dec-91	13.00	0.37	36	11.23326507	1.766734933
Jan-92	16.00	0.01	37	12.5317358	3.4682642
Feb-92	12.00	0.45	38	18.25969873	-6.25969873
Mar-92	9.00	0.28	39	21.54251442	-12.54251442
Apr-92	8.00	0.06	40	24.83886734	-16.83886734
May-92	11.40	0.31	41	27.70229583	-16.30229583
Jun-92	28.60	1.53	42	45.93250567	-17.33250567
Jul-92	19.00	0.25	43	24.93334852	-5.93334852
Aug-92	10.20	0.07	44	20.4090813	-10.2090813
Sep-92	14.30	0.58	45	18.535924	-4.235923999
Oct-92	13.60	0.33	46	12.92899735	0.671002653
Nov-92	13.60	0.21	47	10.30628151	3.293718488

Dec-92	10.20	0.10	48	10.2297253	-0.029725303
Jan-93	8.30	0.69	49	16.59050701	-8.290507007
Feb-93	8.30	0.65	50	20.15972803	-11.85972803
Mar-93	40.00	3.14	51	101.467252	-61.46725203
Apr-93	20.00	1.20	52	36.59668509	-16.59668509
May-93	60.00	1.99	53	59.33151318	0.668486821
Jun-93	150.00	2.73	54	87.77737086	62.22262914
	Seepage	Recharge		Predicted	Residual
Min	5.60	0.01		9.98	-61.47
Max	131.60	3.14		101.47	73.32
Median	18.20	0.41		21.89	0.97
Average	24.44	0.59		24.22	0.70
Total	1445.30	37.78		1445.30	0.00

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Regression Statistics						
Multiple R	0.7078691					
R Square	0.5010787					
Adjusted R Square	0.4711435					
Standard Error	19.026537					
Observations	54					
Analysis of Variance						
	df	Sum of Squares	Mean Square	F	Significance F	
Regression	3	18178.727	6059.57567	16.738737	1.166E-07	
Residual	50	18100.4561	362.009123			
Total	53	36279.1831				
	Coefficients	Standard Error	t Statistic	P-value	Lower 95%	Upper 95%
Intercept	18.44896	2.94317568	6.26838559	6.753E-08	12.537415	24.3605
Recharge^2	8.1856153	1.49002135	5.49362279	1.142E-06	5.1928181	11.17841
Sin(t)	3.4726558	3.79281132	0.91558887	0.3640297	-4.145433	11.09074
Cos(t)	-7.984013	3.8309305	-2.0840924	0.0419879	-15.67867	-0.28936
Amplitude =	8.7065379	3.81187091	2.28405896	0.0133248	1.0608967	16.35218
Offset =	-1.160527	-67.4168304	(days)			
	Max	Jan	Min	Jul

	Sump		Date:	7/26/93	10:36
Month	190 S	Recharge	Observation	Predicted Y	Residuals
Jan-89	0.00	0.15	1	0.64469838	-0.64469838
Feb-89	2.50	0.23	2	1.199617115	1.300382885
Mar-89	3.70	2.14	3	3.158112208	0.541887792
Apr-89	2.20	0.31	4	1.973054091	0.226945909
May-89	0.70	0.75	5	2.176478065	-1.476478065
Jun-89	0.20	1.21	6	2.248080998	-2.048080998
Jul-89	0.60	0.32	7	1.360477868	-0.760477868
Aug-89	0.60	0.41	8	0.839193653	-0.239193653
Sep-89	0.00	1.86	9	1.447658493	-1.447658493
Oct-89	1.30	0.29	10	0.022325605	1.277674395
Nov-89	0.00	0.05	11	-0.044698069	0.044698069
Dec-89	0.00	0.14	12	0.191682792	-0.191682792
Jan-90	0.90	0.70	13	0.800825949	0.099174051
Feb-90	0.90	0.80	14	1.395220007	-0.495220007
Mar-90	0.90	0.19	15	1.638317474	-0.738317474
Apr-90	1.80	0.97	16	2.25537224	-0.45537224
May-90	0.90	1.28	17	2.536026001	-1.636026001
Jun-90	1.80	0.86	18	2.005965114	-0.205965114
Jul-90	0.60	0.59	19	1.442586733	-0.842586733
Aug-90	0.90	0.68	20	0.937543832	-0.037543832
Sep-90	0.30	0.05	21	0.292353008	0.007646992
Oct-90	0.70	0.25	22	0.015107243	0.684892757
Nov-90	1.70	0.04	23	-0.044956913	1.744956913
Dec-90	0.00	0.07	24	0.186575924	-0.186575924
Jan-91	0.00	0.20	25	0.65062766	-0.65062766
Feb-91	0.00	0.15	26	1.189000092	-1.189000092
Mar-91	3.20	1.18	27	2.091570441	1.108429559
Apr-91	8.60	0.51	28	2.027860171	6.572139829
May-91	5.80	2.03	29	3.36563633	2.43436367
Jun-91	3.20	1.15	30	2.200760627	0.999239373
Jul-91	2.90	0.53	31	1.420129608	1.479870392
Aug-91	0.70	0.78	32	0.98633461	-0.28633461
Sep-91	0.40	1.08	33	0.681309085	-0.281309085
Oct-91	0.70	0.30	34	0.023798101	0.676201899
Nov-91	0.00	0.57	35	0.063540148	-0.063540148
Dec-91	0.40	0.37	36	0.231178664	0.168821336
Jan-92	0.00	0.01	37	0.637109494	-0.637109494
Feb-92	0.70	0.45	38	1.249014763	-0.549014763
Mar-92	1.00	0.28	39	1.66609702	-0.66609702
Apr-92	0.50	0.06	40	1.948074402	-1.448074402
May-92	0.70	0.31	41	2.017487399	-1.317487399
Jun-92	1.50	1.53	42	2.529487411	-1.029487411
Jul-92	2.20	0.25	43	1.330388397	0.869611603
Aug-92	0.60	0.07	44	0.767174757	-0.167174757
Sep-92	0.30	0.58	45	0.390592927	-0.090592927
Oct-92	0.30	0.33	46	0.024825733	0.275174267
Nov-92	0.00	0.21	47	-0.026702363	0.026702363

Dec-92	0.00	0.10	48	0.200131069	-0.200131069
Jan-93	0.00	0.69	49	0.815193117	-0.815193117
Feb-93	0.60	0.65	50	1.337982101	-0.737982101
Mar-93	4.50	3.14	51	4.929079819	-0.429079819
Apr-93	3.50	1.20	52	2.428095459	1.071904541
May-93	3.60	1.99	53	3.308772116	0.291227884
Jun-93	4.30	2.73	54	4.23783303	0.06216697
	Seepage	Recharge		Predicted	Residual
Min	0.00	0.01		-0.04	-2.05
Max	8.60	3.14		4.93	6.57
Median	0.70	0.41		1.25	-0.19
Average	1.30	0.59		1.25	0.01
Total	73.40	37.78		73.40	0.00

Regression Statistics						
Multiple R	0.6612121					
R Square	0.4372015					
Adjusted R Square	0.4034336					
Standard Error	1.3177491					
Observations	54					
Analysis of Variance						
	df	Sum of Squares	Mean Square	F	Significance F	
Regression	3	67.4472352	22.4824117	12.947247	2.225E-06	
Residual	50	86.8231351	1.7364627			
Total	53	154.27037				
	Coefficients	Standard Error	t Statistic	P-value	Lower 95%	Upper 95%
Intercept	0.969081	0.20383988	4.75412877	1.568E-05	0.5596564	1.378506
Recharge^2	0.3341834	0.10319662	3.23831752	0.0020772	0.1269068	0.54146
Sin(t)	0.7635441	0.26268436	2.906698	0.0053217	0.2359268	1.291161
Cos(t)	-0.69722	0.26532443	-2.6278011	0.0112159	-1.23014	-0.1643
Amplitude =	1.0339802	0.26400439	3.91652653	0.0001364	0.5044547	1.563506
Offset =	-0.740026	-42.9892322	(days)			
	Max	Feb	Min	Aug		

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