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ENVIRONMENTAL EFFECTS OF THE LEAKAGE FROM

THE 183-H SOLAR EVAPORATION BASIN

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SUMMARY

Four deactivated concrete water treatment basins located in the 100-H Area were designated for use as solar evaporation basins in the early 1970's. The 183-H basins are used for the storage and/or disposal of the routine chemical wastes generated by the UNC Fuels Production Department.

In mid-1977, analysis of groundwater samples from the well closest to the 183-H basin began to show elevated levels of nitrate. These higher nitrate concentrations indicated leakage was occurring from basin No. 1, the only basin in use at the time.

To correct the leakage problem, use of basin No. 1 was discontinued in mid-1978 when basin Nos. 2 and 3 were put into service. The basins were carefully prepared and coated with a urethane liner before being put into use. Basin No. 4 is being prepared in a similar fashion, except that it will be coated with a butyl liner, and should be in service by late 1982.

Environmental effects of nitrate and hexavalent chromium pollution on aquatic organisms are discussed. Both NO_3^- and Cr^{+6} are at least mildly toxic to the early life stages of several salmonid fish species. Adult salmon are much more tolerant of this type of pollution.

The major human health problems associated with nitrate include methemoglobinemia and the formation of N - nitroso compounds. Cr^{+6} ingested by humans may be toxic to the central nervous system, liver, skin, kidney, and the respiratory tract. The National Drinking Water Standards for NO_3^- and Cr^{+6} are 45 ppm (or 10 ppm as Nitrogen) and 0.05 ppm, respectively.

A very simple model was developed to estimate the NO_3^- and Cr^{+6} concentrations in the Columbia River due to leakage from the 183-H Basin. Estimations from this model indicated extremely low concentrations of these pollutants.

It was concluded that the environmental impact from the leakage of the 183-H Solar Evaporation Basin is negligible. The main reasons for the absence of impact include the dilution of pollutants in the groundwater, the low concentrations of pollutants in the river along the shoreline and at mainstream, and the tolerance of these low NO_3^- and Cr^{+6} concentrations by aquatic organisms. In addition, the isolation of 100-H Area from the general public aids in preventing the leakage from contaminating any private or public drinking water supplies.

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1.0 183-H SOLAR EVAPORATION BASIN

Four deactivated concrete water treatment basins located in 100-H Area (see Figure 1.1) were designated for use as solar evaporation basins in
4. the early 1970's. The basins are for storage and/or disposal of the routine chemical wastes generated by the UNC Fuels Production Department (FPD). Prior to use of the 183-H basins, the routine chemical wastes were disposed of via ground disposal in the 300 Area process trenches.

The first shipment of chemical waste discharged to basin No. 1 occurred on June 23, 1973. After two months of use, a leak in a receiving tank in the 300 Area caused a postponement of the use of the evaporation basin until late January 1975. Currently, basins No. 2 and 3 are being used with basin No. 4 expected to be ready for use late in 1982.

1.1 Description of Facility

The dimensions of the basins are given in Figure 1.2. Photographs of the basins are also provided. The total capacity of each basin, at a useable depth of 12 feet, is approximately 450,000 gallons. Wire strands have been installed over the basins at six foot intervals to discourage waterfowl landings. The entire group of four basins is surrounded by a six foot high chain link fence topped by three strands of barbed wire.

Basin No. 1 was modified for chemical waste use by permanently plugging the drain and installing a tank truck discharge line. This basin was taken out of service in August 1978 due to a leakage problem. By that time, basins No. 2 and 3 had been prepared to accept the neutralized chemical wastes.

Basins No. 2 and 3 were prepared by first permanently plugging all drains and sandblasting the wall surfaces. Basin walls were then covered with one coat of Carboline No. 295 W.B. surfacer and coated with at least 40 mils of Carboline X1304-146 urethane lining. The tank truck discharge line was also extended to service these basins.

With the advent of increased fuel production, basins No. 2 and 3 are being filled at a rate faster than anticipated. This has necessitated the use of basin No. 4 for evaporation of chemical waste. Minor seepage through the wall from basin No. 3 to 4 is evident after nearly four years of service. Although not significant in itself, the seepage is indicative of either permeability or degradation of the lining in basins 2 and 3, so that a different lining will be used for basin No. 4.

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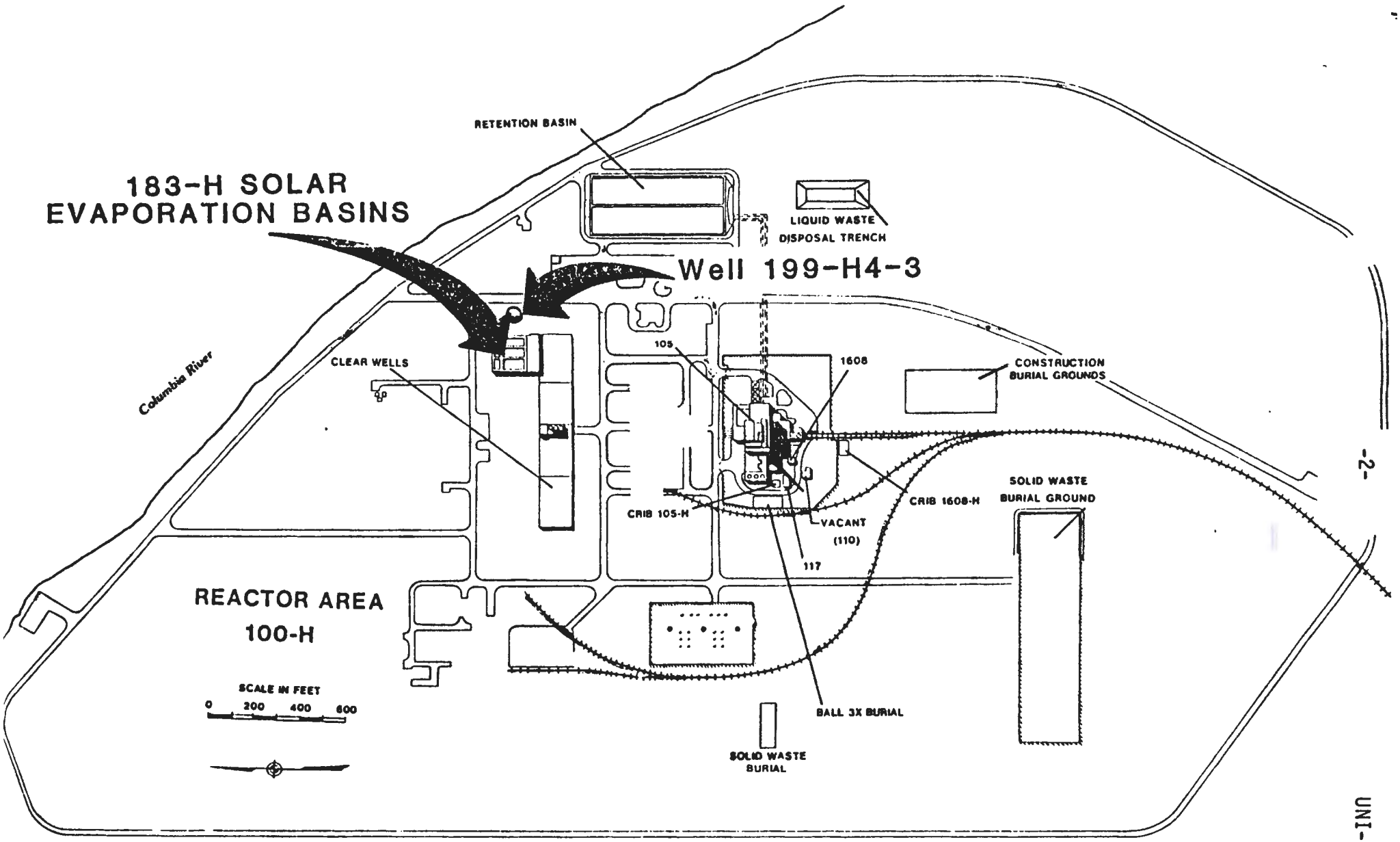
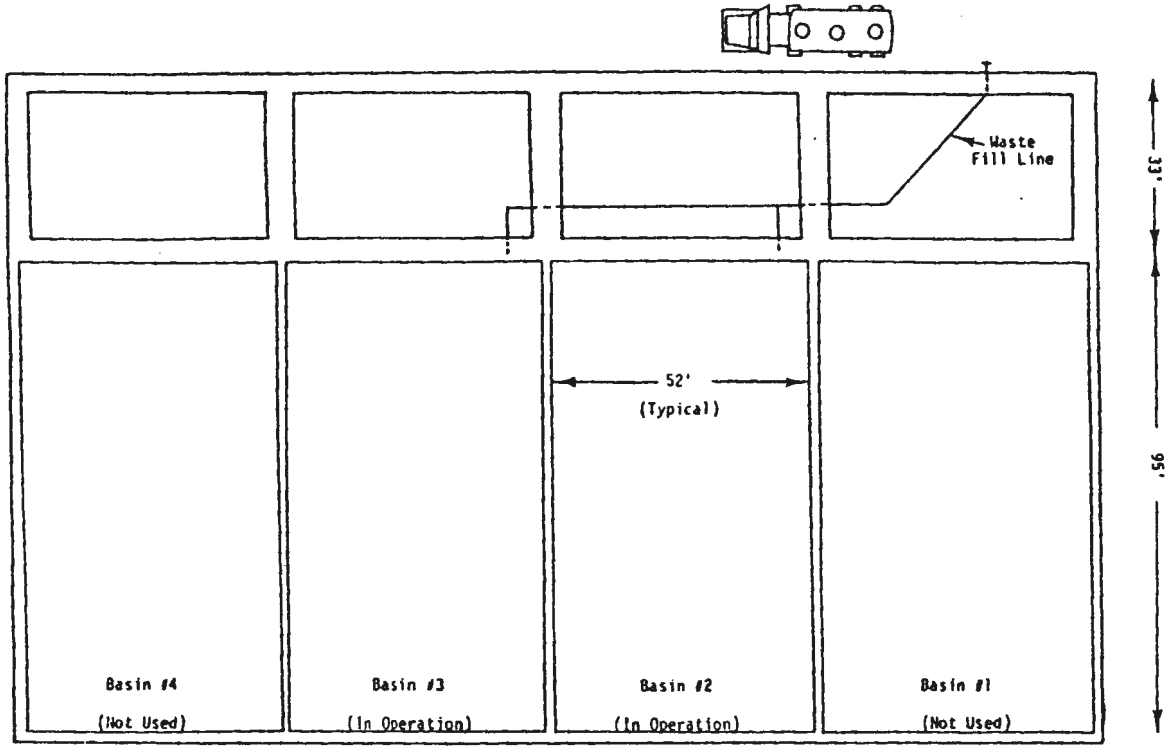


Figure 1.1. Plan of 100-H Area Showing 183-H Basins and Groundwater Well 199-H4-3.

TOP VIEW OF 183-H SOLAR EVAPORATION BASIN



SIDE VIEW OF 183-H SOLAR EVAPORATION BASIN

- Capacity of one basin of maximum fill level is approximately 450,000 gallons.
- Basin walls are covered with one coat of Carboline #295 U.B. Surfacer and coated with at least 40 mils of Carboline X1304-146 urethane lining.
- Wall Thickness:
  - Walls and floor of shallow section are 1' thick
  - Floor of deep section is 6" thick
  - Outside walls and walls between basins are 2' thick at the bottom and 1' thick at the maximum fill level.

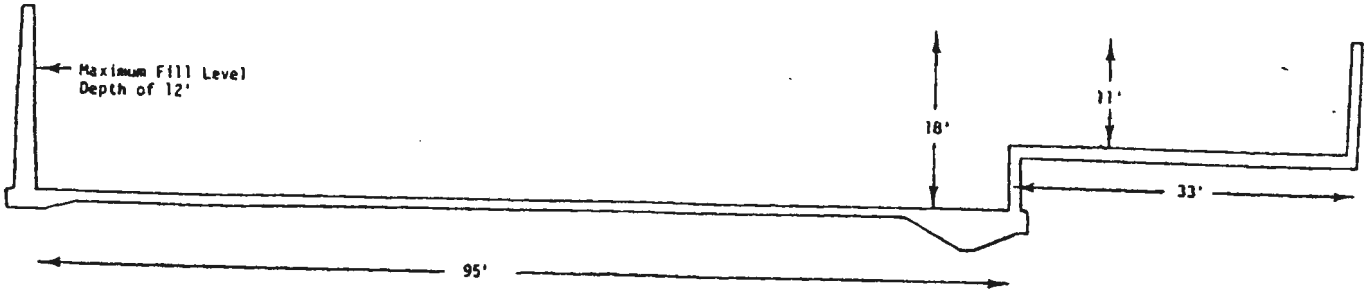


Figure 1.2. Dimensions of the 183-H Solar Evaporation Basins

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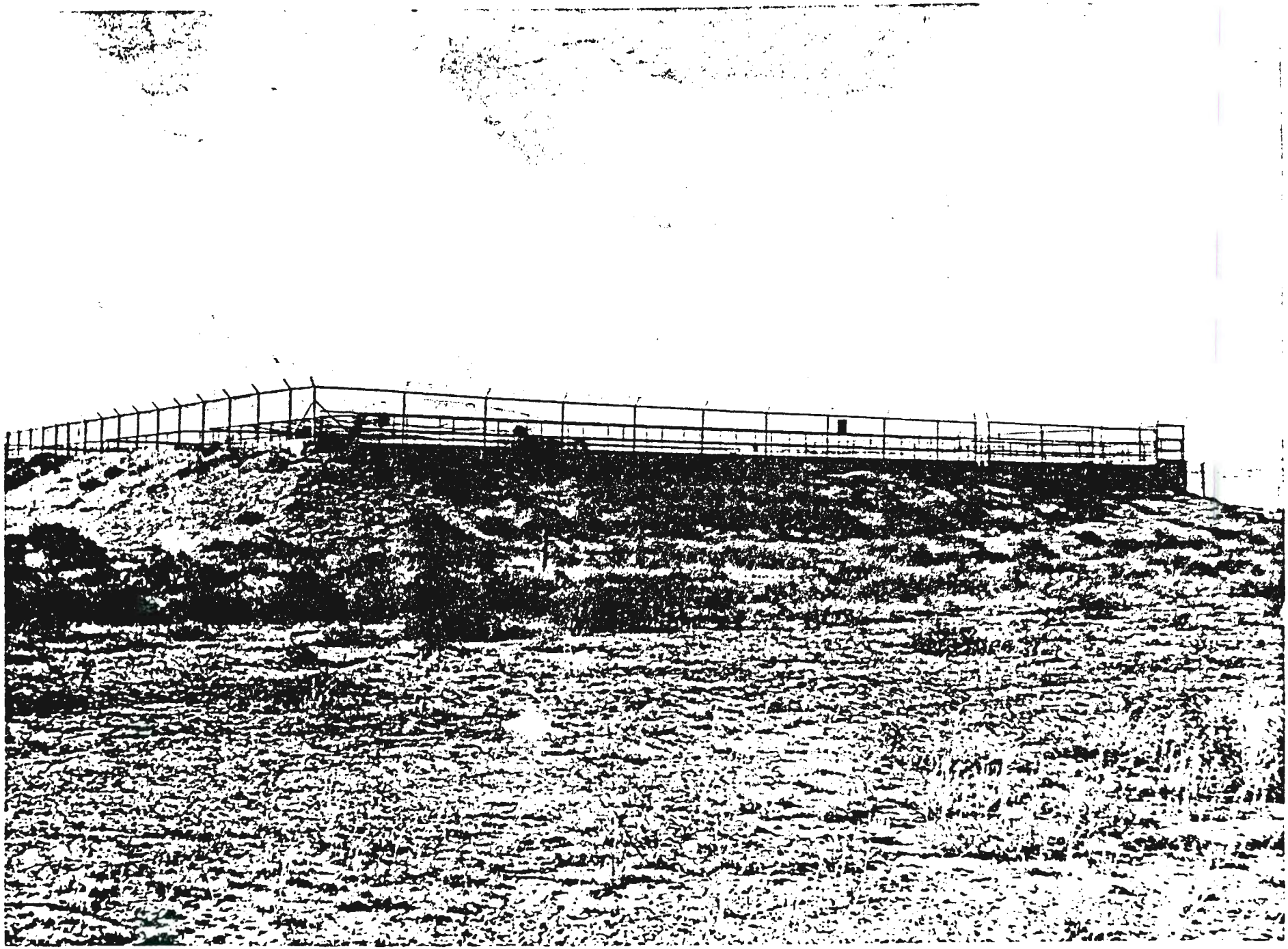
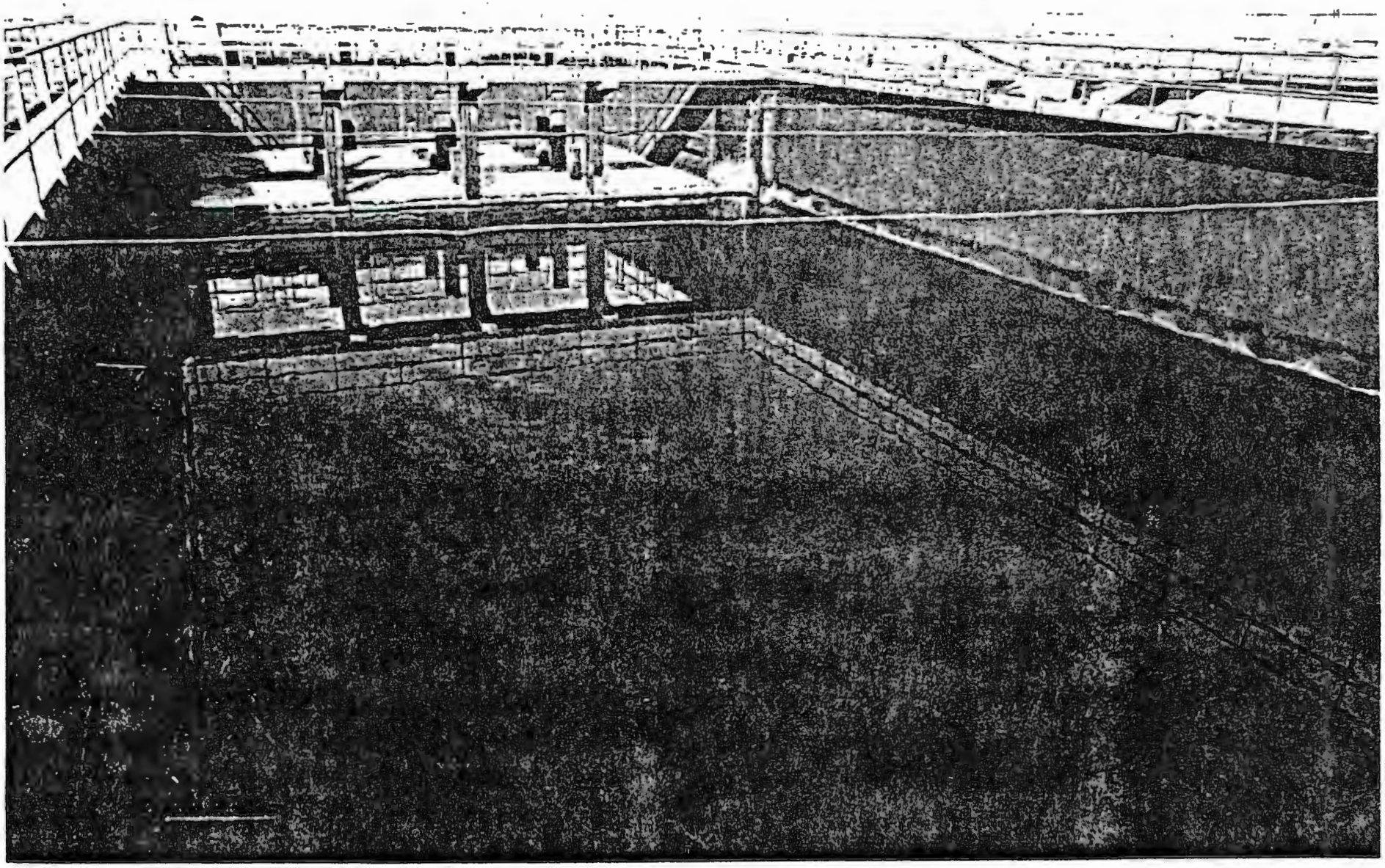
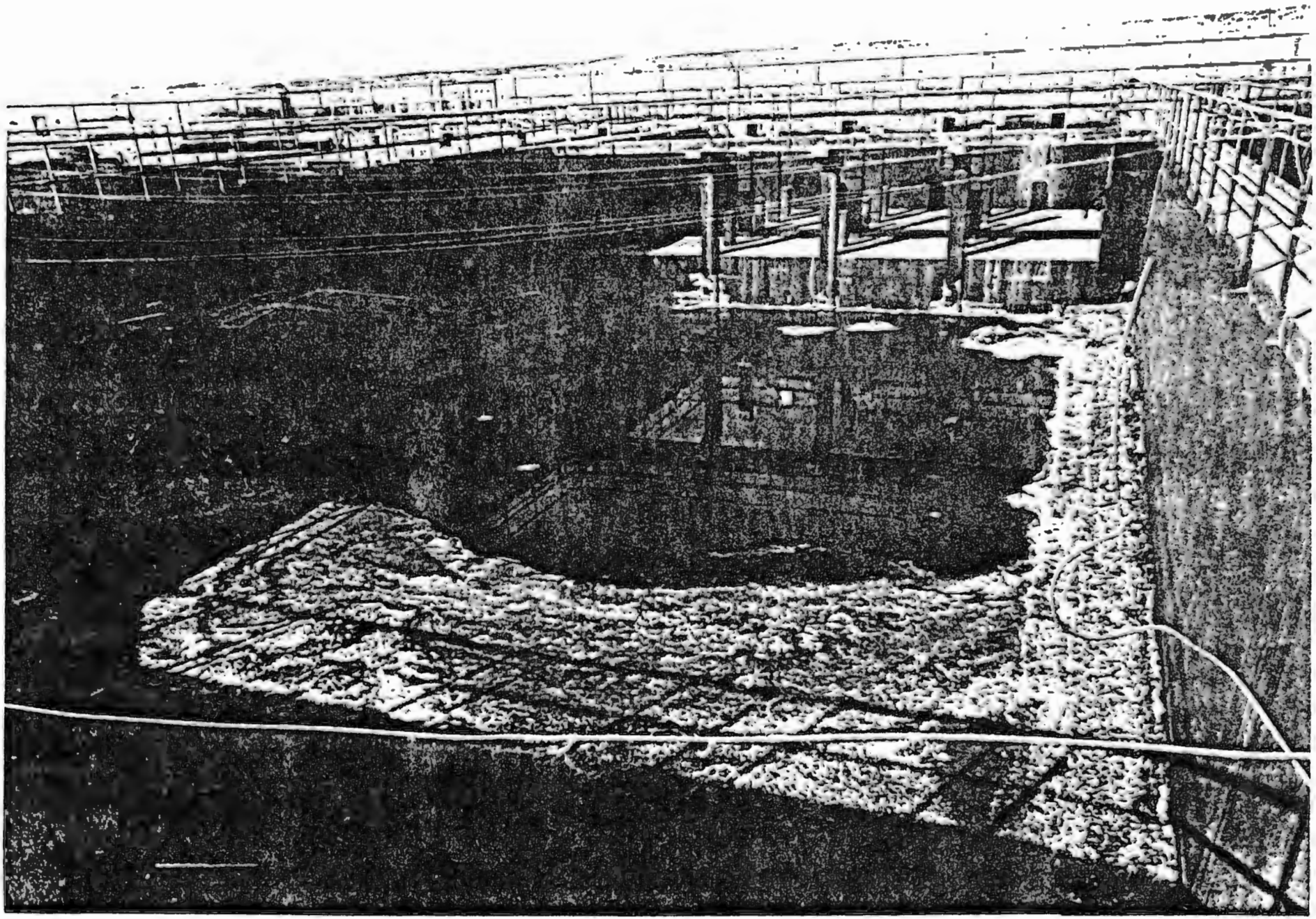


View of the 183-H Solar Evaporation Basins from Outside the Security Fence



View of Basin No. 2



View of Basin No.3 Showing Crustal Layer Forming Over Liquid Surface

Basin No. 4 is to be prepared by plugging drains, sandblasting, sealing significant cracks with an epoxy - polysulfide caulk (Carboline #225), surfacing with an epoxy surfacer (Carboline #295 WB), applying a tie coat (Carboline #1340 Clear), then applying 40 mils of Butyl elastomer coating (Carboline Chem-Elast #5501) with 20 mils of Hypalon elastomer coating (Carboline Chem-Elast #5011) for ultraviolet protection. The tank truck discharge line will be extended from basin No. 3 to 4.

1.2 Composition of Wastes Discharged to 183-H Basins

Neutralized chemical waste is routinely generated in the fuel fabrication process at FPD facilities in the 300 Area. The quantities of routine wastes that have been discharged to the solar evaporation basins through CY-1981 are presented in the following table.

Table 1.1 Amounts of Routine Waste Discharged to the 183-H Solar Evaporation Basins (taken from UNC Annual Effluent Release Reports).

Year	Gallons	Litres
1981	200,000	757,000
1980	150,000	570,000
1979	160,000	604,000
1978	150,000	570,000
1977	155,000	588,000
1976	134,000	508,000
1975	142,000	540,000
1973	8,000	30,000
TOTAL	1,099,000	4,167,000

The routine neutralized chemical wastes contain high concentrations of nitrates and copper due to the use of nitric acid and copper stripping procedures in the fuel fabrication process.

Smaller quantities of hazardous wastes such as hexavalent chromium are also present in the routine wastes. The chromium is due to the etching of stainless steel by $HF-HNO_3$ acid and the disposal of about 250 gal/yr of "Zinctone" and 50 gal/yr of "Kleen-ox" solution. The quantities of the more important materials discharged to the 183-H basins during 1981 are listed in Table 1.2.

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Table 1.2 Quantities of Materials Discharged to the 183-H Solar Evaporation Basin in CY 1981.

Material	Pounds	Kg
Ammonium ion	260	120
Fluoride ion	12,700	5,760
Nitrate ion	253,000	115,000
Chromium	150	70
Copper	38,200	17,300
Manganese	340	160
Sulfate ion	50,800	23,030
Uranium	520	240

Starting in December 1975, FPD began disposing of some of the waste chemicals from other Hanford contractors on a work order basis. These waste chemicals were placed in the 183-H Solar Evaporation Basins. The service was restricted to nonradioactive wastes (other than unirradiated uranium) that are water soluble, nonflammable, nonexplosive, and are compatible with UNC's waste solutions.

A Chemical Waste Disposal Permit is filled out for each type of waste chemical by the person requesting disposal. FPD personnel determine if compatability tests and/or analyses are required and what disposal procedures must be used. The waste chemicals are not accepted until all the appropriate approval signatures are obtained on the disposal permit.

Through this chemical waste disposal service, several hazardous wastes (as defined in Environmental Protection Agency Hazardous Waste Regulations) have been placed in the 183-H Solar Evaporation Basins. A list of the hazardous wastes placed in the basin is presented in Table 1.3.

Table 1.3. Hazardous Wastes in the 183-H Basins

Date	Permit Number	Waste
01-05-82	2-82	50 gal of silk screen cleaner with 26 ppm Pb
12-03-81	3-81	1 1/2 gal Cu HD-120 (90 ppm Cr) and 3/4 gal Red Zr-130 (80 ppm Cr)
11-26-80	6-80	47 gal of hydrazine in 1,200 gal of boiler cleaning solutions
10-02-80	4-80	100 gal of silk screen cleaner with 60 ppm Pb
02-01-80	1-80	500 gal of liquid with 30 ppm Cr
10-30-79	5-79	40 oz/gal chromic acid - 75 lbs. total
05-08-78	6-78	$HgCl_2$ - 0.9 lbs total
05-23-77	13-77	450 gallons with 100 ppm Cr and 10 ppm Pb
05-06-77	12-77	16 gallons of used battery acid containing Pb
04-13-77	11-77	Potassium dichromate ($K_2Cr_2O_7$) - 2 lbs Sodium dichromate ($Na_2Cr_2O_7$) - 1 lb
03-22-77	10-77	300 gallons of used battery acid containing Pb
03-09-77	8-77	Chromic Acid (CrO_3) - 6 lbs
03-09-77	7-77	*Potassium Cyanide - ½ lb (1 kg List)*
03-09-77	6-77	Sodium Chromate (Na_2CrO_4) - 4 lbs Barium Perchlorate ($Ba(ClO_4)_2$) - 4 lb
03-07-77	5-77	*Sodium Cyanide (NaCN) - 1 lb (1 Kg list)* *Cuprous Cyanide ($CU_2(CN)_2$) - 1 lb (1 Kg list)*
10-11-76	32-76	300 gallons of used battery acid containing Pb
08-17-76	29-76	185 gallons of used EDTA solution with 100 ppm Pb
08-17-76	27-76	Mercuric nitrate $Hg(NO_3)_2$ - 1/8 gallon
08-05-76	26-76	60 gallons of used battery acid containing Pb
07-12-76	24-76	Solution with 10 ppm Cr - 39 lbs Solution with 10 ppm Cr and 6 ppm Cd - 15¼ gallons
06-29-76	22-76	Ni Acid Solution with 10 ppm Cr - 1 pt
03-25-76	20-76	Flake Chromic Acid (CrO_3) - 100 lbs
02-20-76	8-76	275 gallons of used battery acid containing Pb
02-17-76	7-76	52 gallons of used battery acid containing Pb
02-02-76	6-76	140 gallons of used battery acid containing Pb
01-30-76	5-76	240 gallons of used battery acid containing Pb
01-19-76	4-76	Used absorbing solution with 1.34 lbs Hg
01-15-76	3-76	*Unused CYANIDE solutions - 2 gallons (1 Kg list)*
07-12-76	25-76	Acid Solution with 80 ppm Cr - 1½ gallons

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2.0 HISTORY OF LEAKAGE FROM BASIN NO. 1

Groundwater well 199-H4-3 is located within 200 feet of the 183-H Solar Evaporation Basins (refer to Figure 1.1). This well is included in the Battelle Pacific Northwest Laboratory (PNL) well sampling program and is sampled on a routine basis.

On July 29, 1977, PNL notified UNC of high nitrate levels in well 199-H4-3. At that time, basin No. 1 was the only basin in use. The high nitrate levels indicated that this basin was leaking.

2.1 Nitrate and Hexavalent Chromium Concentrations in Groundwater

Since the initial high nitrate levels were detected, PNL has been sampling well 199-H4-3 approximately once per month. The concentrations of nitrates and hexavalent chromium are shown graphically in Figure 2.1 and listed in Table 2.1.

The concentrations of both NO_3^- and Cr^{+6} peaked in the summer of 1978 and have not approached those high levels since. Leakage from basin No. 1 has resulted in a groundwater plume that is chemically contaminated and is moving hydraulically downgradient towards the Columbia River.

At its closest point, the 183-H basins are approximately 600 feet from the river. PNL has reported low transmissivity values for the soil at 100-H Area which indicates the groundwater is moving slowly near the 183-H basins. PNL scientists have estimated that the groundwater probably moves less than 200 feet per year (personal communication, A. E. Reisenauer, 6/28/82).

The groundwater flow also slows down as it approaches the river and is dramatically effected by river elevation. During low river flows the groundwater enters the river, however, at high river levels, "bank storage" occurs where river water flows back into the groundwater and the groundwater flow reverses direction (for the groundwater close the riverbank).

The slow speed of groundwater flow at 100-H Area is significant since it will take a long time for the chemicals which leaked from basin No. 1 to reach the river. For example, the portion of the groundwater plume with the high NO_3^- and Cr^{+6} concentrations reported in mid-1978 has probably not yet reached the river.

2.2 Corrective Action to Mitigate Leakage

Shortly after the high nitrate concentrations were detected in the groundwater, a leaking water line was discovered between the 183-H basins and the adjacent well. The underground water line was repaired by September 9, 1977.

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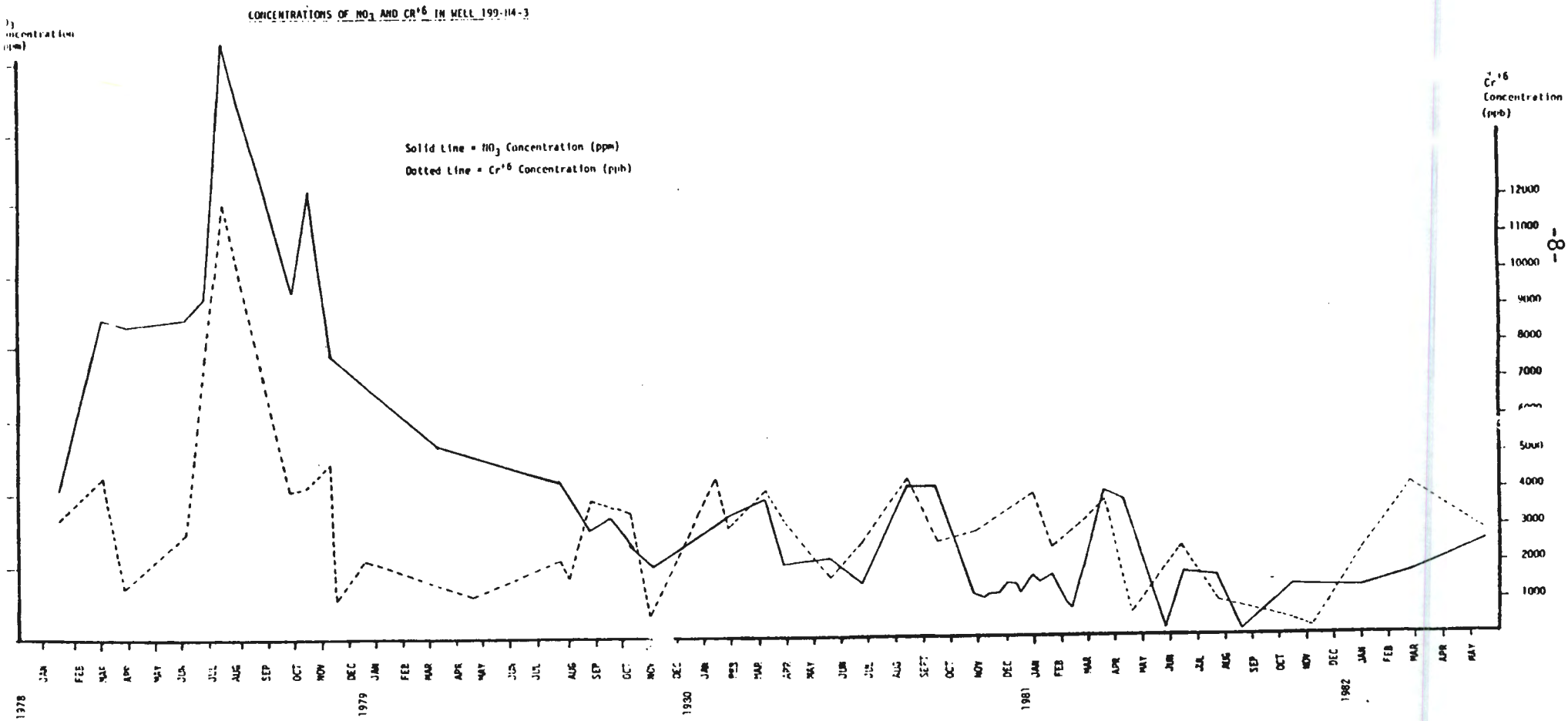

Figure 2.1. Nitrate and Hexavalent Chromium Concentrations from Well 199-H4-3.

Table 2.1. Nitrate and Hexavalent Chromium Concentrations from Well 199-H4-3.

Date	NO_3^- (ppm)	Cr^{+6} (ppb)	Date	NO_3^- (ppm)	Cr^{+6} (ppb)
	MDWS 45 ppm	MDWS .05 ppm - 50 ppb			
1/17/78	2100	3300	01/07/81	770	*
2/28/78	4400	4400	01/19/81	820	2500
3/27/78	4300	1500	02/04/81	530	*
6/02/78	4400	2900	02/10/81	430	*
6/23/78	4700	6400	2/26/81	1200	3400
7/12/78	8400	12000	3/17/81	2300	3700
9/25/78	4800	4100	4/16/81	2100	770
10/11/78	6200	4200	5/29/81	64	*
11/06/78	3900	4800	6/19/81	980	2800
11/13/78	*	1100	7/20/81	910	1100
12/21/78	*	2200	8/20/81	39	*
2/06/79	*	1900	10/13/81	700	410
3/05/79	2700	*	11/09/81	*	120
4/17/79	*	1100	01/05/82	720	2700
7/19/79	2200	2100	02/26/82	950	4300
7/31/79	*	1750	05/20/82	1400	2900
8/23/79	1500	3800			
9/12/79	1700	3700			
10/05/79	1300	3500			
11/01/79	1000	860			
1/08/80	*	4400			
1/25/80	1700	3200			
3/4/80	1900	4100			
3/31/80	1100	3400			
5/15/80	1200	1700			
6/24/80	710	2600			
8/14/80	2100	4300			
9/11/80	2100	2500			
10/29/80	660	2900			
11/04/80	620	*			
11/11/80	630	*			
11/18/80	660	*			
12/01/80	750	*			
12/10/80	740	*			
12/15/80	620	*			
12/31/80	820	3900			

* = No Sample

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At the time it was felt that water from the leaking underground water piping was causing chemicals which had leaked from the basin to return to solution and enter the groundwater rather than remain bound and immobilized in the soil column. Since the nitrate levels remained high after the leaking water line was repaired, it now appears the water from that source had less influence in mobilizing leaked chemicals to the groundwater than originally thought.

To correct the leakage problem basins Nos. 2 and 3 were carefully prepared and covered with a urethane lining as described earlier. Liquid waste in basin No. 1 was then pumped into basin No. 2.

It should be mentioned that only a small portion of the wastes in basin No. 1 could be pumped. The material in this basin consisted of three district phases as follows: (1) a crystalline phase on top of the liquid that was estimated to be up to six inches thick and primarily $NaSO_4$, (2) a precipitate of heavy metals (mainly oxides and hydroxides) in the bottom of the basin, and (3) a liquid supernate which was primarily a saturated solution of $NaNO_3$. The wastes which could not be pumped out of basin No. 1 are still contained within this basin.

Basin No. 4 will be prepared for use during 1982. Since the time when the other two basins were lined with a urethane liner, it has been found that butyl compounds resist degradation from ultraviolet radiation more favorably, hence, basin No. 4 will be lined with a butyl liner.

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3.0 ENVIRONMENTAL EFFECTS OF NITRATE POLLUTION

Most forms of nitrogen are very soluble in water. The main sources of nitrate in water are natural aerosols (e.g. ammonium sulfate), precipitation, fixation by microrganisms, organic matter, agricultural and industrial wastes, and rocks. The relative importance of each of these contributors varies between regions. Figure 3.1 is a graphic diagram of the nitrogen cycle.

The nitrate concentration in groundwater is typically higher than surface waters since groundwater is often in contact with rocks from which nitrate is leached. The following table gives some typical nitrate concentrations.

Table 3.1 Typical Nitrate Concentrations Found in the Environment (Osteryoung, 1972).

Reservoir	Nitrate (ppm)
Surface Water	0-100
Groundwater	0-1000
Igneous Rock	200
Sedimentary Rock	2200
Peat	70,000
"Unpolluted" Water	5-10

The most important non-agricultural sources of nitrate pollution are domestic sewage and percolate from refuse (as from a sanitary landfill). Most of man-made nitrate pollution originates from non-point sources, which are the most difficu' pollution sources to identify and control.

3.1 Effects of Nitrate on Aquatic Organisms

Normally, the concentrations of nitrate actually in solution in a stream or river are low because the ions are rapidly taken up by plants. For example, observations in the Volga River show the nitrate concentration may fall to zero in the summer and rise to over 1 ppm during the winter when plants are not active (Hynes, 1970).

Ecological effects of nitrates are mostly concerned with eutrophication -- and eutrophication is usually only a problem in lakes. Phosphorous and nitrogen are the most important nutrients that stimulate overenrichment leading to the undesirable water quality changes characteristic of eutrophication.

Kincheloe, et al (1979) found that nitrate is at least mildly toxic to the early life stages of several salmonid species. In their experiments, they tested the egg and early fry stages of chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*) and anadromous (Steelhead) and nonanadromous rainbow trout (*Salmo gairdneri*). Results of their experiments are shown in Table 3.2.

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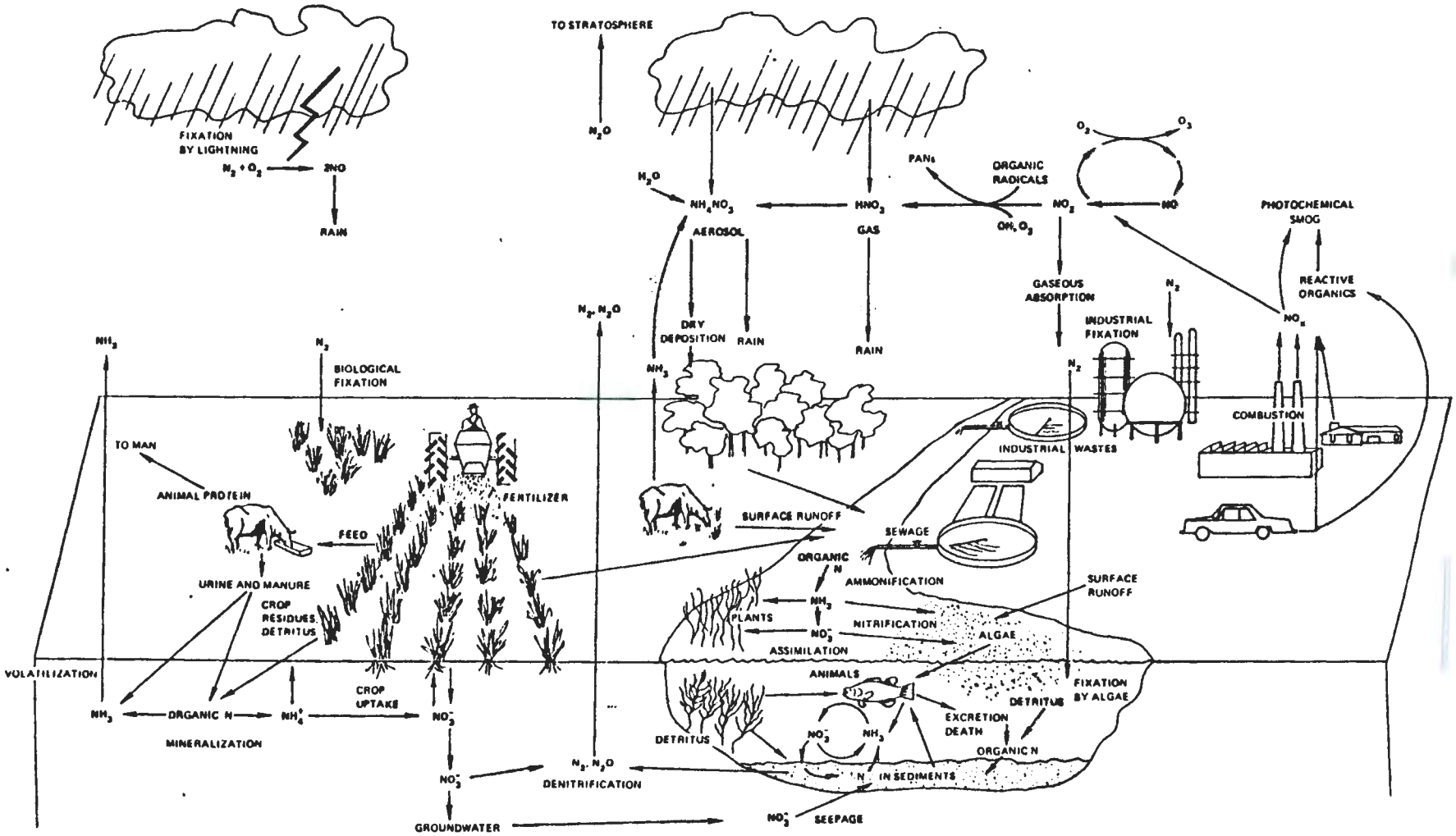

Figure 3.1. (from National Academy of Sciences, 1978)

Schematic representation of the nitrogen cy le, emphasizing human activities that affect fluxes of nitrogen.

Table 3.2 Egg and Fry Mortality due to Incubation in Nitrate Containing Water. Significant Mortalities at the P = 0.05 level.

Species and Life Stage	Nitrate Concentration at which Significant Mortality Occurs
Chinook Salmon Fry	20 ppm
Steelhead Trout Eggs	5 ppm
Rainbow Trout Eggs and Fry	10 ppm
Coho Salmon Eggs and Fry	no significant mortalities up to 20 ppm

Westin (1974) performed a series of experiments to determine the median tolerance limit concentrations for the survival of several species of adult salmonids. Her results indicate that adult fish are much more tolerant of nitrate exposure than the early life stages. The four day and seven day median tolerance limit concentrations were 5800 ppm and 4800 ppm, respectively, for chinook salmon and 6000 ppm and 4700 ppm, respectively, for rainbow trout.

Toxicity of nitrate to other aquatic organisms is presented in Table 3.3.

Table 3.3 Toxicity of Nitrate (Hohreiter, 1980).

Organism		Nitrate mg/l	Remarks	Reference
Invertebrates				
Planaria	*(Polycelis nigra)*	1000	48 hour TLm.	18
Cladocera	*Daphnia magna*	5000	Immobilized in 48 hours.	16
"	" "	665	96 hour TLm, acute.	200
Snail	*Biomphalaria alexandrina*	6000	Lethal, 24 hours, acute.	201
"	*Bulinus truncatus*	3100	Lethal, 24 hours, acute.	201
"	*Lymnaea sp.*	3251	96 hour TLm, acute.	200
Fish				
Mosquito fish	*(Gambusia affinis)*	6650	96 hour TLm, acute.	193
Goldfish	*(Carassius auratus)*	1282	Lethal in 14 hours.	202
Bluegill	*(Lepomis macrochirus)*	9400	96 hour TLm, small fish.	68
"	" "	10,000	96 hour TLm, medium fish.	68
"	" "	9000	96 hour TLm, large fish.	68
"	" "	2000	LC_{50}, 96 hours, sodium nitrate.	203
"	" "	420	LC_{50}, 96 hours, potassium nitrate.	203
Rainbow trout	*(Salmo gairdneri)*	1060	LC_{50}, 7 days, fingerlings.	204
Chinook salmon	*(Oncorhynchus tshawytscha)*	1080	LC_{50}, 7 days.	204
Recommended Standards or criteria				
Domestic		10*		14
			General Remarks	
			a. Nitrate is converted to nitrite (which is 10 times more toxic than nitrate) by bacteria in nature.	14,185
			b. Nitrate, under proper conditions, can serve as a precursor in the microbial formation of nitrosamines in natural waters. (Nitrosamines are known carcinogens, mutagens, teratogens, and acute toxicants).	185
			* c. Standard for drinking water is 10 mg/l. At 20 mg/l, methemoglobinemia (blue baby disease) is common in infants. Standard employs a very narrow safety factor of 2, and perhaps a lower standard should be considered for waters that will be used for drinking.	185

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3.2 Nitrates and Human Health

The adverse health effects related to nitrate involve, as a first step, the reduction of nitrate to nitrite. The major health problems associated with nitrate include methemoglobinemia and the formation of N-nitroso compounds.

Methemoglobinemia is a disease which results in the reduction of the oxygen-carrying capacity of the blood. This disease occurs when an oxidizing agent such as nitrite, formed in the stomach from nitrate, combines with hemoglobin to form methemoglobin.

Infants are especially susceptible to methemoglobinemia due to low gastric acidity which promotes nitrite formation in vivo from ingested nitrate and from their increased susceptibility of hemoglobin to methemoglobin formation. Infants in the first three months of life are most susceptible to the disease while adults normally are not.

Nearly all cases of methemoglobinemia in the United States resulted from ingestion of nitrate in private well water used to make infant formula. The disease is quite rare when water supplies contain less than 10 ppm NO_3^- (as Nitrogen), however, it can be common in infants at concentrations of 20 ppm.

Nitrate concentrations above 10 ppm are rare in public water supplies in the United States. Some private drinking water wells on small farms may contain up to several hundred ppm of nitrate. The national drinking water standard for nitrate is 45 ppm, which corresponds to 10 ppm for nitrate as nitrogen.

Nitrite can also react with other substances to form N-nitroso compounds. Of these compounds, it appears that the N-nitrosamines pose the most significant threat to human health. The general and acute toxicity, teratogenicity, mutagenicity, and carcinogenicity of a variety of nitrosamine compounds is well established. The carcinogenicity of nitrosamines has not been conclusively proven for humans.

Other human health problems associated with nitrate concentrations have also been observed. Hypertension mortality and prevalence were found to be higher in river basins with greater water hardness and higher nitrate concentrations. It has also been suggested that nitrate poisoning (methemoglobinemia) may be responsible for 10-20% of the Sudden Infant Death Syndrome victims up to three months of age in Czechoslovakia (Osteryoung, 1972).

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4.0 ENVIRONMENTAL EFFECTS OF CHROMIUM POLLUTION

Chromium is found in the environment through natural means as well as man-made pollution. Concentrations of chromium in the earth's crust range from 10-100 ppm while this metal is found in river water at concentrations of 0.001-0.8 ppm. The cycling of chromium is presented below.

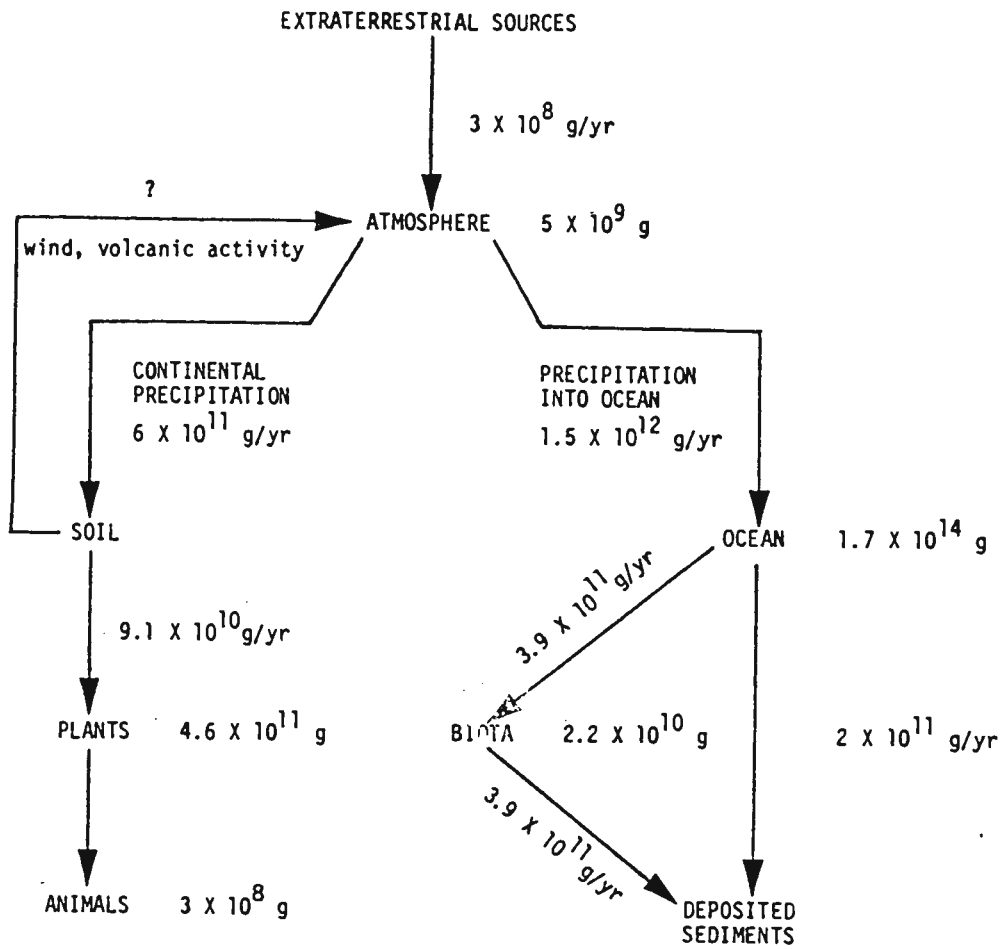

Figure 4.1 Natural Biogeochemical Cycling of Chromium (Furst, 1981).

Trivalent chromium is the most stable form of chromium under the redox conditions normally found in natural waters and sediments. Cr^{+3} in natural waters usually precipitates quickly due to the formation of insoluble hydroxides or oxides.

Hexavalent chromium is a strong oxidizing agent and is always found in an aqueous solution as a component of a complex anion. Cr^{+6} present in most natural waters (pH >6.5) will be in the form of the chromate ion $(CrO_4)^{-2}$.

In natural waters, most of the Cr^{+3} is absorbed on to particulate matter whereas most of the Cr^{+6} stays in solution. For this reason, Cr^{+3} is usually found in river sediments while Cr^{+6} is found in river water.

4.1 Effects of Chromium on Aquatic Organisms

Studies on the environmental fate of chromium have indicated that this metal is accumulated in aquatic biota to levels much higher than in the ambient water. One study found the food chain to be a more efficient pathway for the uptake of chromium than direct uptake of seawater. A study in Narragansett Bay, Rhode Island, found that phytoplankton concentrated chromium more than other organisms. In addition, the bioaccumulation factor for the uptake of chromium by fish is known to be very high.

In a study of the effects of chromium on aquatic plants, Mangi, et al (1978) found Cr^{+6} to be moderately toxic to several riverine algae and less toxic to duckweed. Growth of all plants was inhibited by a Cr^{+6} concentration of 10 ppm. The uptake of chromium varied approximately linearly with the concentration of Cr^{+6} present in the water. Adsorption was largely responsible for the "uptake" since dead plant cells also removed chromium from the water. The accumulation of Cr^{+6} by both living and dead plant matter could be an important mechanism for lowering Cr^{+6} concentrations in river water.

Tests by Benoit (1976) indicated that rainbow trout were slightly more sensitive to Cr^{+6} than brook trout (*Salvelinus fontinalis*). One week old rainbow and brook trout alevins were exposed to Cr^{+6} concentrations of 0.34 ppm and 0.76 ppm. Both species exposed to the higher concentration died within the first three months. Growth weight was retarded at 0.20 ppm as eight month old rainbow and brook trout weighed 30% and 20% less than controls, respectively. The mean 96 hour LC_{50} for Cr^{+6} for 14 month old rainbow trout was 69 ppm and for five month old brook trout the mean 96 hour LC_{50} was 59 ppm.

The toxicity of chromium to other aquatic organisms is listed in Table 4.1.

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Table 4.1. Toxicity of Chromium (Hohreiter, 1980).

Organism		Chromium mg/l	Compound	Remarks	References
Algae					
	Scenadesmus	0.7	$K_2Cr_2O_7$	Threshold effect.	59
Diatom	*(Navicula)*	0.21	$K_2Cr_2O_7$	Soft water TLm.	60
"	"	0.25	$K_2Cr_2O_7$	Hard water TLm.	60
Protozoa	*(Microregma)*	0.21	$K_2Cr_2O_7$	Threshold effect.	42
Invertebrates	*Daphnia*	0.7	$K_2Cr_2O_7$	Threshold effect.	59
	Daphnia magna	0.016	$Na_2Cr_2O_7$	Toxic threshold.	5
	" "	0.05	-	Lethal in 6 days.	61
	" "	<<0.10	$Na_2Cr_2O_7$	Toxic threshold.	16
	" "	<<0.10	Na_2CrO_4	Toxic threshold.	16
	" "	0.51	Na_2CrO_4	Toxic threshold.	62
Amphipod	*(Gammarus pulex)*	1.4	Na_2CrO_4	Total mortality.	63
Snail (General)		17.3	$K_2Cr_2O_7$	Soft water TLm.	60
" "		40.6	$K_2Cr_2O_7$	Hard water TLm.	60
Planaria	*(Polycelis nigra)*	148	CrO_4	Toxic threshold.	64
Fish					
Goldfish	*(Carassius auratus)*	52	CrO_3	Toxic in 30 min.	65
"	" "	104	CrO_3	Toxic in 6 to 84 hours.	5,69
"	" "	177	$K_2Cr_2O_7$	Toxic in 3 days.	65
Bluegill	*(Lepomis macrochirus)*	50	-	Toxic limit for 30 day exposure.	66
"	" "	70	-	Toxic limit for 1 week's exposure.	66
"	" "	75	$K_2Cr_2O_7$	Died within 4 days.	8
"	" "	103	$K_2Cr_2O_7$	96-hour TLm.	68 ,71
"	" "	145	$Na_2Cr_2O_7$	24-hour TLm.	70
"	" "	148	$Na_2Cr_2O_7$	Toxic limit.	5
"	" "	213	$Na_2Cr_2O_7$	48-hour TLm.	71
"	" "	300	Na_2CrO_4	24-hour TLm.	70
"Sunfish" (General)		110	$K_2Cr_2O_7$	96-hour TLm.	46,72
" "		113	$K_2Cr_2O_7$	96-hour TLm.	60
" "		135	$K_2Cr_2O_7$	96-hour TLm, hard water.	60
" "		170	K_2CrO_4	96-hour TLm.	46,72
Fish (Continued)					
Rainbow trout	*(Salmo gairdneri)*	20	$K_2Cr_2O_7$, K_2CrO_4	Toxic.	22,69,73
Brown trout	*(Salmo trutta)*	5.2	$K_2Cr_2O_7$	Toxic.	74
Trout (General)		50	$K_2Cr_2O_7$	Lethal in 33 hours.	8
" "		100	K_2CrO_4	24-hour TLm.	75
" "		100	$K_2Cr_2O_7$	Lethal after 6 hours.	8
Fish (General)		5	-	Toxic.	
Goldfish	*(Carassius auratus)*	37.5	LC_{50}, 96 hours.		33
Guppy	*(Poecilia reticulata)*	30.0	LC_{50}, 96 hours.		33
Bluegill	*(Lepomis macrochirus)*	71.9	LC_{50} 96 hours, Cr^{+3}		33
"	" "	110.	TLm 96 hours, acute, soft water. (Alkalinity and hardness reduced toxicity.)		46
"	" "	170	Chromate, 96 hour TLm, acute, soft water.		46
"	" "	113.0	96-hour, TLm (dichromate).		47
"	" "	176.8	96-hour, 100% kill (dichromate).		47
"	" "	0.2	96-hour, TLm, continuous exposure.		48
"	" "	118	LC_{50}, Cr^{+6}, 96 hours, soft water.		33
"	" "	133	LC_{50}, Cr^{+6}, 96 hours, hard water.		33
Stickleback	*(Gasterosteus aculeatus)*	1.0	"Toxic limit", acute		49
"	" "	1.2	Lethal limit.		6, 7
"	" "	1.3	Survived only 1 week.		6
"	" "	2.0	Survived only 2 days.		6
"	" "	2.4	Lethal limit.		43
"	" "	5.0	Survived only 1 day.		6
Largemouth bass	*(Micropterus salmoides)*	195	TLm, 48 hours.		53
" "	" "	94	TLm, 80 hours.		53
Rainbow trout	*(Salmo gairdneri)*	69.0	TLm, 96 hours.		54
	" "	69.0	LC_{50}, 96 hours, soft water.		55
"	" "	0.40	Reproductive impairment, 2 years.		54
"	" "	5.0	40% killed, 15 days (chromate).		56
"	" "	10.0-12.5	80% killed, 15 days.		56
Brook trout	*(Salvelinus fontinalis)*	50.0	TLm, 96 hours.		54
"	" "	59.0	LC_{50}, 96 hours.		55
"	" "	0.40	Reproductive impairment, 2 years.		54
Chinook salmon	*(O. tschawytscha)*	0.2	Alevins and juveniles, survival significantly reduced.		57
Coho salmon	*(O. kisutch)*	17.8	Cr^{+6}, toxic.		58
"Young salmon"		<10.0	Minimum lethal concentration.		58
Recommended standards or criteria					
Domestic		0.05			14,15
Stock watering		5.0			15
Fish and aquatic life		0.1			14
Fish		1.0			15
Aquatic life besides fish		0.05			15

General Remarks

Toxicity of chromium and its compounds to aquatic biota depends on the valence of chromium and on

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4.2 Chromium and Human Health

Trivalent chromium functions bilogically as an essential element in mammals where it helps to maintain efficient glucose, lipid, and protein metabolism. The average daily human food intake of chromium is about 250 μg/day.

Adverse human health effects due to chromium are mainly due to Cr^{+6}, which is much more toxic than Cr^{+3}. The target organs for hexavalent chromium include the central nervous system, liver, skin, kidney, and the respiratory tract.

Cr^{+6} is a suspect carcinogen as some authors have associated tumors in humans with chromium exposure. Cr^{+6} is also a teratogen since it concentrates in the fetus.

Chromium concentrations in uncontaminated water average about 1 ppb while municipal drinking water often contains up to 35 ppb. Human toxicological responses are not expected at these chromium concentrations. The National Drinking Water Standard for chromium is 50 ppb.

4.3 Chromium and Other Metals

To get an idea of the toxicity of chromium compared to other metals, Tables 4.2 and 4.3 are presented to show how chromium compares to seven other toxic trace elements.

The tables were prepared by Koranda, et al (1981) and show a comparison of chromium, arsenic, calcium, lead, selenium, nickel, vanadium, and uranium. Except for uranium, chromium was found to be the least toxic of these elements.

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Table 4.2. Toxicity parameters for eight toxic metals.

Element	ACA[a] (ppm)	Soil[b] (ppm)	DWS[c] (μg/liter)	IRR HHO[d] (μg/liter)	Daily intake[e] (μg)	Aquatic toxicity (mg/liter)	Plant toxicity (ppm)	Mammalian toxicity	Human toxicity	FISH BIOACCUM[f]
Arsenic	1.8	6	0.05	0.1	900	0.02	0.5-2	11.2 ppm 1-25 mg/kg	125 mg 0.06-1.18 mg/kg	333
Cadmium	0.2	0.06	0.01	0.01	72	0.01-10	0.1-3	72 mg/kg	3 mg/d	200
Chromium	100	100	0.05	0.1	284	0.03-64	0.5-24	1870 mg/kg	4000 ppm	4000
Nickel	75	40	0.05	0.2	500	0.03	25-100	1-3 g/kg	--[g]	100
Lead	13	10	0.05	0.1	300	0.01-50	25-30	0.5-0.8 ppm	1.7 mg/kg	300
Selenium	0.05	0.2	0.01	0.02	200	2	5-20	6 mg/kg	0.7-7 mg/d	167
Uranium	1.8	1	0.1	0.5	1.3	2.8	50+	400 mg/kg	1-4% diet	10
Vanadium	135	100	0.1	0.1	1160	4.8	10-40	50 mg/kg	not known	10

[a]Average crustal abundance.
[b]Average soil concentration.
[c]Drinking water standard.
[d]Continuous irrigation water standard.
[e]Daily intake from food, air, and water.
[f]Bioaccumulation factor for fishes.
[g]Toxic only as the carbonyl; some cutaneous sensitivity.

Table 4.3. Toxicity matrix.

	Toxicity parameters									
	ACA[a]	Soil[b]	DWS[c]	IRR HHO[d]	Daily intake	Aquatic toxicity	Plant toxicity	Mammalian toxicity	Human toxicity	FISH BIOACCUM[e]
HIGH	Vanadium	Chromium	Cadmium	Cadmium	Vanadium	Cadmium	Cadmium	Lead	Arsenic	Chromium
	Chromium	Vanadium	Selenium	Selenium	Arsenic	Lead	Arsenic	Arsenic	Lead	Arsenic
	Nickel	Nickel	Arsenic	Lead	Nickel	Arsenic	Chromium	Selenium	Selenium	Lead
	Lead	Lead	Lead	Arsenic	Lead	Nickel	Selenium	Cadmium	Cadmium	Cadmium
	Arsenic	Arsenic	Chromium	Chromium	Chromium	Chromium	Vanadium	Vanadium	Chromium	Selenium
	Uranium	Uranium	Nickel	Vanadium	Selenium	Selenium	Lead	Uranium	Uranium	Nickel
	Cadmium	Cadmium	Uranium	Nickel	Cadmium	Uranium	Nickel	Chromium	Vanadium	Uranium
LOW	Selenium	Selenium	Vanadium	Uranium	Uranium	Vanadium	Uranium	Nickel	Nickel	Vanadium

Toxicity Ranking

(1) Arsenic: High daily intake; high plant, mammalian, and human toxicity; and bioaccumulation toxicity for fish
(2) Cadmium: High drinking water, irrigation water, aquatic, and plant toxicity
(3) Lead: High aquatic, mammalian, and human toxicity
(4) Selenium: High drinking water and irrigation water toxicity
(5) Nickel: No high toxicity or concentrations
(6) Vanadium: High daily intake
(7) Chromium: High bioaccumulation toxicity in fish
(8) Uranium: No high toxicity or concentrations

[a]Average crustal abundance.
[b]Average soil concentration.
[c]Drinking water standard.

5.0 ENVIRONMENTAL IMPACT OF 183-H BASIN LEAKAGE

From monitoring groundwater well 199-H4-3, it is known that a groundwater plume currently exists beneath 100-H Area that contains high concentrations of NO_3^- and Cr^{+6}. Although the adverse impacts to the environment from this contaminated plume are difficult to assess, it appears there will be no detectable adverse environmental impacts due to the leakage from the 183-H Solar Evaporation Basin.

5.1 Estimate of River Concentrations Near 100-H Area

PNL groundwater scientists were contacted to perform computer modelling of the groundwater flow beneath 100-H Area. As part of this modelling, the volume and concentration of contaminated groundwater entering the Columbia River was to be estimated. Unfortunately, since only two wells exist at 100-H Area, PNL felt they could not perform such modelling.

To obtain a rough estimate of the effect the contaminated groundwater plume may have on the river and river biota, a simple model was developed. Several assumptions were made concerning the contaminated groundwater plume, so that the estimates derived from the model should only be considered estimates of what could be occurrly in the river rather than an estimate of the actual condition.

The conditions for the model are listed in Table 5.1 and presented graphically in Figure 5.1.

Table 5.1 Assumptions Used in Making Estimates of NO_3^- and Cr^{+6} Concentrations in Columbia River.

- polluted groundwater plume approaching river along a front 200 ft long and 10 ft. wide.
- groundwater speed = 200 ft/yr = 16.6 ft/mo = 0.56 ft/day
- so, rate at which polluted groundwater plume enters river is:

  200 ft X 10 ft X 0.56 ft = 1120 ft^3/day = 8378 gal/day
  = 350 gal/hr
  = 5.8 gal/min

- characteristics of water entering river:
  - slope of riverbed is 30°, so a 30°-60°-90° triangle is formed (see Figure 5.1)
  - side of triangle opposite 60° angle is 17.3 ft. long.
  - area of triangle is 86.5 ft^2.
- then, volume of river water directly exposed to the polluted groundwater plume is

  200 ft X 86.5 ft^2 = 17,300 ft^3 = 130,000 gal

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Table 5.1 (cont.)

- river flow along shoreline is 1 ft/sec
- so, total volume of water exposed to polluted groundwater plume in 1 minute is

  130,000 + (130,000) (30%) = 170,000 gal

- so, 5.8 gal of polluted groundwater is diluted by 170,000 gal of Columbia River water
- resulting river concentrations along shoreline at NO_3^- concentrations of 8400 ppm and 3000 ppm

$$\frac{5.8 \text{ gal}}{170{,}000 \text{ gal}} \times 8400 \text{ ppm} = \underline{\underline{0.29 \text{ ppm}}} \qquad \frac{5.8 \text{ gal}}{170{,}000 \text{ gal}} \times 3000 \text{ ppm} = \underline{\underline{0.10 \text{ ppm}}}$$

- resulting river concentrations along shoreline at Cr^{+6} concentrations of 12,000 ppb and 4000 ppb.

$$\frac{5.8 \text{ gal}}{170{,}000 \text{ gal}} \times 12{,}000 \text{ ppb} = \underline{\underline{0.41 \text{ ppb}}} \qquad \frac{5.8 \text{ gal}}{170{,}000} \times 4000 \text{ ppb} = \underline{\underline{0.14 \text{ ppb}}}$$

Using this simple model, very low NO_3^- and Cr^{+6} concentrations were observed. At NO_3^- concentrations of 8400 ppm and 3000 ppm in the polluted groundwater, concentrations of 0.29 ppm and 0.10 ppm, respectively, were estimated in the river along the shoreline. With Cr^{+6} concentration of 12,000 ppb and 4000 ppb in the groundwater plume, concentrations along the river shoreline were 0.41 ppb and 0.14 ppb, respectively.

It should be noted that a degree of conservatism is built into this simple model with the high concentrations of NO_3^- and Cr^{+6} in the groundwater entering the river. Once the polluted groundwater plume has travelled the 600 feet to the river, it should be much more dilute than the concentrations detected in well 199-H4-3.

Taking the model one step further, the dilution of the leakage from the basin relative to the entire river can be calculated. To do this, the concentrations calculated to be in the parcel of water along the shoreline (170,000 gal) were diluted in the lowest average monthly river flow that occurred in CY-1981 (83,100 cfs, which equals 621,600 gal/sec).

The river concentrations of NO_3^- and Cr^{+6} which result from these calculations are included in Table 5.2.

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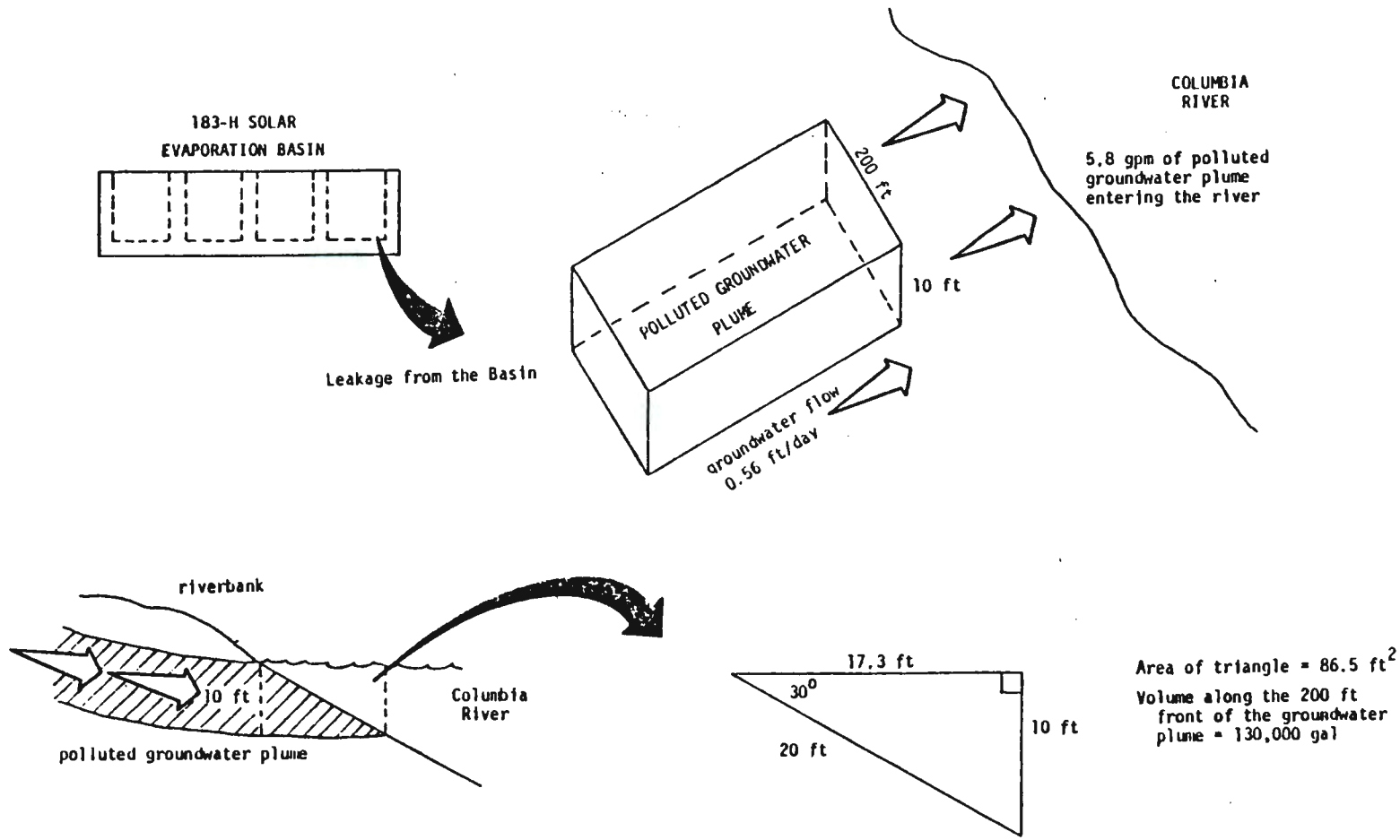

Figure 5.1. Model Used to Estimate Pollutant Concentrations in the River.

Table 5.2. NO_3^- and Cr^{+6} concentrations calculated to be in the Columbia River from 183-H Basin Leakage.

Pollutant	Groundwater Concentration	Shoreline Concentration	River Concentration
NO_3^-	8,400 ppm	0.29 ppm	1.3×10^{-3} ppm
NO_3^-	3,000 ppm	0.10 ppm	4.6×10^{-4} ppm
Cr^{+6}	12,000 ppb	0.41 ppb	1.9×10^{-3} ppb
Cr^{+6}	4,000 ppb	0.14 ppb	6.4×10^{-4} ppb

The calculations in Table 5.2 indicate the leakage from the basin has had no effect on the water quality of the Columbia River. The calculated river concentrations are insignificant compared to the concentrations observed in the river (section 5.3) and are most likely below PNL detection levels.

5.2 Environmental Effects on Fish near 100-H Area

Of the salmonid fish species that live in the Columbia River, only steelhead trout and the fall race of chinook salmon spawn in the Hanford Reach of the river. Steelhead spawn from February through May at Hanford. The time of emergence of steelhead fry from the redds is not well known.

The fall race of chinook salmon have several well known spawning areas in the Hanford Reach of the Columbia River, which are depicted in Figure 5.2. Chinook salmon spawn from September through mid-November at Hanford. Fry typically begin emergence from redds in March.

As can be seen in Figure 5.2, there are several chinook salmon spawning areas near 100-H Area. Although spawning areas may be near the area where polluted groundwater is entering the river, no adverse effects on egg or juvenile salmonid survival should be occurring. Even if the estimates made in the model in the previous section are off by an order of magnitude or more, the NO_3^- concentrations, and especially the Cr^{+6} concentrations, should be well below concentration levels which other authors have found to cause adverse effects.

Adult salmonids and other fish species are much more tolerant of NO_3^- and Cr^{+6} concentrations than the early life stages. No adverse effects should occur to adult fish from the 183-H basin leakage entering the Columbia River.

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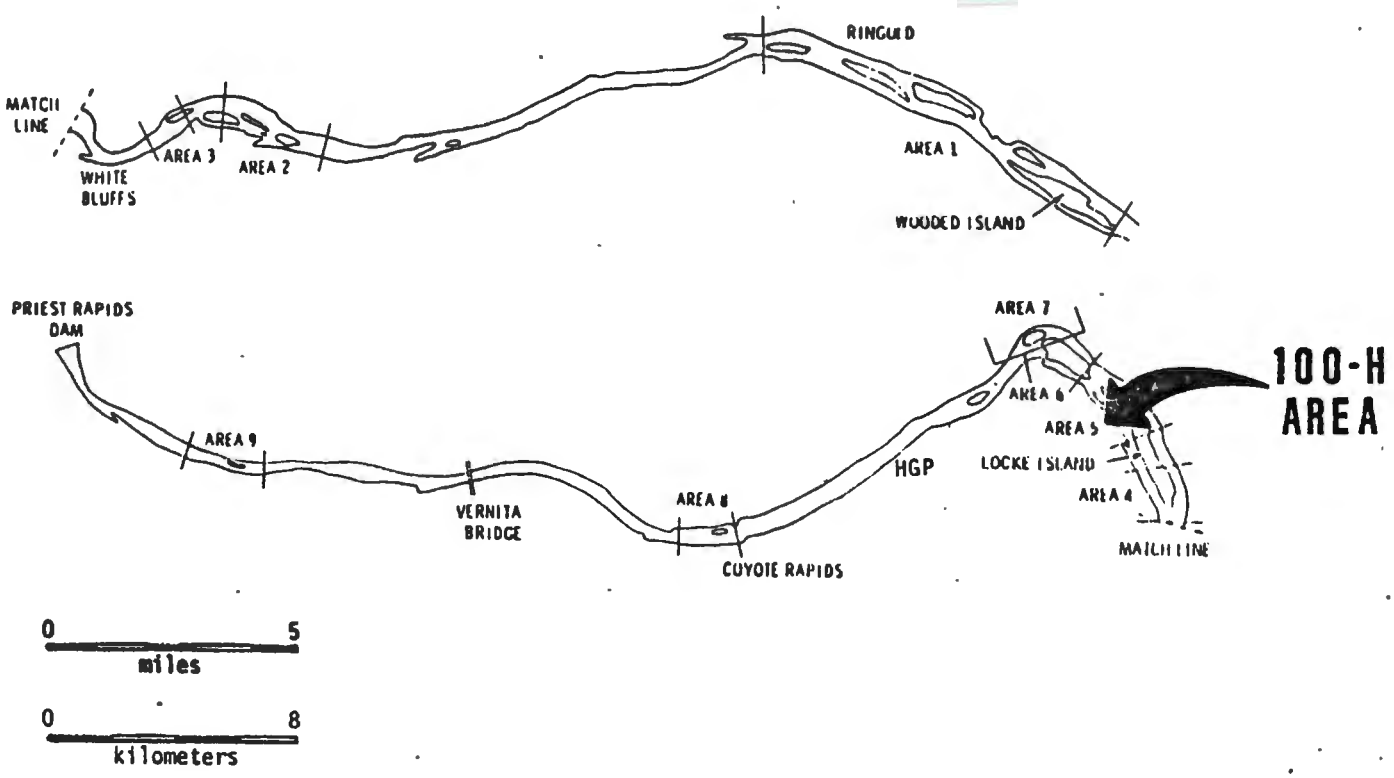

Figure 5.2. Major Fall Chinook Salmon Spawning Areas in the Hanford Reach of the Columbia River (from Watson, 1976)

5.3 Nitrate and Chromium Concentrations Observed in the Columbia River

As part of the PNL Environmental Surveillance Program, water samples taken at the Vernita Bridge (upstream of 100-H Area) and at Richland (downstream of 100-H Area) have been analyzed for NO_3^- concentrations, and during 1981 the samples were also analyzed for total chromium concentrations. As can be seen in Table 5.3, leakage from the 183-H Solar Evaporation Basin has had no effect on the nitrate and chromium concentrations in the Columbia River.

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Table 5.3 Nitrate and Chromium Concentrations in the Columbia River (taken from the annual PNL Environmental Surveillance Reports).

NO_3^- Concentrations (ppm)

	Vernita Bridge		Richland	
Year	Max	Avg.	Max.	Avg
1981	0.53	0.19 ± 0.03	0.60	0.19 ± 0.04
1980	0.71	0.26 ± 0.15	0.64	0.25 ± 0.14
1979	4.4	0.38 ± 1.2	0.80	0.35 ± 0.41
1978	0.82	0.29	1.4	0.33
1977	0.43	0.25	0.74	0.25
	Chromium, total (ppb)			
1981	20	8.0 ± 7.5	20	8.0 ± 7.5

5.4 Environmental Impact of Leakage from 183-H Basin

From the previous discussion it can be seen that any environmental impact from the leakage of the 183-H Solar Evaporation Basin is very low or negligible, and probably undetectable.

The main reasons for this negligible impact include the dilution of pollutants in the groundwater and the river, the low concentrations of pollutants in the river along the shoreline, and the tolerance of these low NO_3^- and Cr^{+6} concentrations by aquatic biota. In addition, the isolation of 100-H Area and the isolation of the groundwater at 100-H Area from the general public aid in preventing the leakage from the basin from contaminating any public water supplies. There are no drinking water wells in use at or near 100-H Area.

It should also be noted that the routine chemical wastes generated by FPD were disposed of to ground disposal trenches (without liners) in the 300 Area before the 183-H basins were put into use. The 300 Area is much closer to the City of Richland and its river intake for their drinking water supply than 100-H Area. Detrimental effects to Richland's drinking water supply were not observed during the time the routine wastes were discharged to ground.

Nonetheless, two followup items to this report will be pursued to further assess the impact of the leakage from the 183-H basin. First, additional groundwater wells are planned for installation at 100-H Area. Once the wells are in place, PNL will be contacted to complete a computer model of the groundwater at 100-H area and

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develop estimates similar to those presented in the model in Section 5.1. This computer model should be a significant improvement over the simple model presented in this report.

Secondly, river water samples will be collected along the shoreline at 100-H Area and analyzed for NO_3^- and Cr^{+6} concentrations. Samples will be collected in October or November which will allow a few months for the groundwater in the area to be moving towards the river due to the low river elevations.

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