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AN OIL SPILL FOCUSES ATTENTION ON THE PROBLEMS OF A MAN-MADE RECREATIONAL LAKE

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ABSTRACT

When a runaway diesel engine fell into a turntable pit at a railroad maintenance facility, its oil tanks ruptured releasing 4,000 gallons of No. 2 diesel oil that subsequently flowed through sewers to an agricultural stream that led to an inland, man-made lake; two days later the lake residents awoke to find "wall to wall" oil covering the water surface. The oil quickly disappeared, but not the anger of the property owners who sued the railroad for $1.2 million to dredge the oil-containing sediments "from the lake bottom," claiming not only that the spill had added oil to the benthic sediments but also chronic pollution from poorly designed and operated wastewater treatment units had impacted the lake. To obtain data for the pending court suit, the defense attorneys assembled a team of scientists and engineers who used a *systems approach* to evaluate the lake, its water quality inputs into it, and impact of the oil on it.

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Man-made recreational lakes are often subjected to many environmental stresses—runoff from farm land, urban runoff, pollution by sewage, industrial wastes and even contamination from small boats. These stresses are often amplified in man-made lakes due to their small volumes, shallow depths, and relatively large volumes of drainage to them.

One of these man-made lakes, Holiday Lake in north central Ohio, was subjected not only to all of these stresses, but also received the full brunt of an oil spill that completely covered the lake surface. The source of the oil was a runaway diesel engine that fell into a turntable pit at the maintenance facility of a railroad in Willard, Ohio. When the engine's oil tanks ruptured, approximately 4,000 gal of fuel oil were released and subsequently flowed through sewers to a small agricultural stream draining into Holiday Lake. Residents reported the lake was completely covered with oil not long after the spill. Within a relatively short period of time, however, visible evidence of the oil spill disappeared.

In addition to the obvious time and effort required by residents to clean up boats, docks and beaches, the Holiday Lake Community Association claimed that the spill had caused long-term and permanent damage to the lake's ecosystem. Oil was reported on the lake bottom and fish caught in the lake were reported to taste of oil. A $1.2 million damage suit was filed by the Community Association against the railroad. This amount was required, they said, to pay for dredging the lake bottom to remove the oil-polluted sediment.

To assist in defending the railroad in this legal action, a team of environmental experts was assembled by the lawyers to study the impact of the oil spill on the lake. This team consisted of an environmental/chemical engineer, ecologist and a chemical engineer with many years experience in oil technology. In assessing the environmental impact, the scientists had the responsibility of first determining the magnitude of the oil problem in the lake, and then evaluating the importance of the oil relative to the ecology of the lake.

It was soon apparent that the lake suffered from a variety of stresses including that caused by the oil. In order to evaluate the importance of the oil impact, the damage caused by the oil had to be assessed along with the damage caused by other environmental stresses.

In this article, the authors' focus is on the methodology used by the investigative team, their reasoning and the conclusions reached.

HOLIDAY LAKE

Physical Setting

Holiday Lake is a man-made recreational lake created by constructing an earthen dam and concrete spillway on the west branch of the Huron River. The configuration of the lake with its branching arms is shown in Figure 1. There are

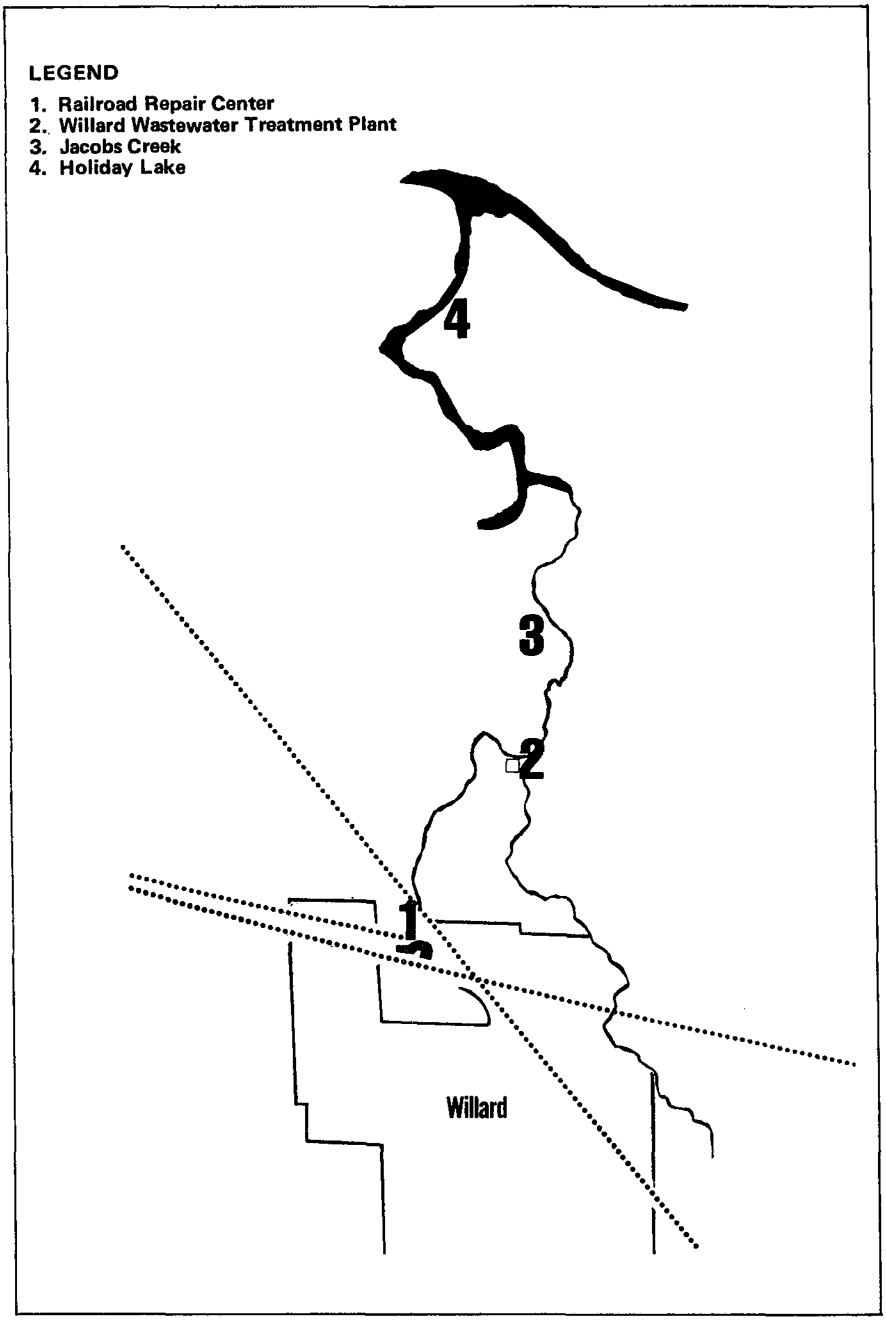

Figure 1. Site of the oil spill near the city of Willard in north central Ohio.

approximately twelve miles of shoreline and approximately 220 acres of water. The maximum depth is reported to be 40 ft with a total water volume estimated at almost 3,000 acre-ft.

The watershed of the west branch of the Huron River upstream from Holiday Lake contains 13.4 mi^2 of mostly agricultural land. Of considerable importance is the fact that within this watershed is the town of Willard, Ohio. Willard, which is the site of the Repair Facility, has a population of about 5,500. Urban drainage in Willard is by both storm and combined sewers. On Jacobs Creek, upstream from Holiday Lake, is the Willard Wastewater Treatment Plant. This plant treats approximately 900,000 gal/day.

In addition to the urban and agricultural land-use in the watershed, the area immediately surrounding the lake consists of 155 homes situated in a recreational community of over 1,400 lots. These homes are all serviced by septic tanks and soil infiltration systems for wastewater disposal.

Soils in the watershed are developed in glacial till and are stoney, silty clays and clay loams. They have poor infiltration capacities and are rated by the Soil Conservation Service as having moderate to severe limitations for septic tank installation. Visible evidence of rills and gulleys on bare soils in the area indicates the soils are susceptible to erosion and no doubt have a higher than average sediment loss rate.

Holiday Lake Hydrology

Holiday Lake has a low lake-area to drainage-area ratio. For each acre of lake there are approximately 40 acres of watershed draining into the lake. As a result, pollutants dispersed within the watershed can be concentrated in the lake.

In this portion of Ohio, the average annual runoff is 11.5 in. according to the Ohio Department of Natural Resources. On the average, Holiday Lake receives 363 million ft^3/yr of runoff. Based on the lake volume, the average residence time of this water is 130 days. As a result of this relatively small residence time, Holiday Lake responds relatively quickly to increases in an influx of pollutants.

Using U.S. Geological Survey streamflow data for nearby gaged rivers, an estimated flow-duration curve for stream runoff to Holiday Lake was determined. Added to the natural streamflow is the constant output of the Willard Wastewater Treatment Plant. Estimated flows are given in Table 1.

In terms of total flow, the wastewater plant effluent is only 14 percent of the streamflow. However, approximately 35 percent of the time, the sewage component of inflow is equal to or larger than the natural streamflow. On an average annual basis, this means that about 128 days of each year the sewage effluent comprises 50 percent or more of the total inflow to the lake. Hence, the total period the lake receives over one-half of its water from the sewage plant is equivalent to the residence time; therefore it is entirely possible that once each year the waters of Holiday Lake are composed of 50 percent sewage effluent.

Table 1. Source and Estimated Inflow of Surface Water to Holiday Lake

Input Source	*Flow Rate*	
	MGY	*Percent*
Wastewater Treatment Plant Effluent	325	11
Groundwater	230	7
Rural Storm	2,099	69
Urban Storm	395	13
	3,049	100

Streamflow into Holiday Lake has several origins: rural storm runoff, urban storm runoff, groundwater inflow and the Willard Wastewater Treatment Plant effluent. While the inflow of the latter is well-known, the magnitude of the other components can only be estimated. Based on the configuration of the flow-duration curve the groundwater component is estimated at about 230 million gallons per year (MGY); the total inflow is 3,049 MGY. Subtracting the treatment plant effluent (325 MGY) and the groundwater component, the remainder is storm runoff. This is subdivided into urban and rural storm runoff on the basis of drainage area, and the knowledge that urban drainage is more efficient than rural drainage and that urban areas are more impervious. The resultant inflow estimates are summarized in Table 1.

DESCRIPTION OF THE WILLARD WASTEWATER TREATMENT PLANT

The Willard Wastewater Treatment Plant is located one mile upstream from Holiday Lake. Between the lake and the plant there is little dilution of the plant effluent except in wet weather.

Willard employs a secondary biological treatment system to treat its wastewater. The plant consists of bar screens, comminutors, grit removal channels, primary sedimentation tanks, trickling filters, secondary sedimentation tanks and a chlorination system. Sludge disposal facilities include a thickener, anaerobic digesters and a centrifuge; wet sludge cake is disposed of on local farms.

The wastewater flowing to the plant was characterized by Willard's consultants as having [1]:

Flow	0.85 mgd	average
	0.41 mgd	minimum
	3.90 mgd	maximum daily, wet weather
BOD_5	229 mg/l	average
Suspended Solids	207 mg/l	average
Phosphorus	12 mg/l	average

The overall plant efficiency report showed BOD and suspended solids removal efficiencies of 91.2 percent and 81.3 percent respectively with effluent concentrations averaging 37 mg/l BOD and 20 mg/l suspended solids.

Bypassing of sewage at the plant due to hydraulic overload or equipment problems, coupled with storm water overflow through Willard's combined sewers via several diversion chambers, increased the load of untreated or partially treated sewage to the stream (and hence the lake).

RAILROAD DISCHARGE

At the time of the study, the railroad's discharge was 40,000 gal/day (14 MGY) from its lagoon, most of it having gone through an API, oil-water gravity separator and a dissolved air flotation unit to remove free and emulsified oil; the air flotation unit became operational only after the spill, so the oil and grease levels in the effluent reported here are significantly lower than at the time of the spill.

Some of the 40,000 gal/day and the pollutants therein discharged by the railroad are attributable to the City of Willard since an overflow from one of their sewer diversion boxes[1] ran through the railroad's sewer line and to their lift station which pumped it into the lagoon. The pump could handle several hundred gal/min and lift it to the lagoon; beyond the pump capacity, the water overflowed to the stream. In almost any storm, the city's sewers overflowed the diversion box to the railroad pump which worked to its capacity putting the storm water into the lagoon.

SAMPLING AND ANALYSES FOR CHEMICAL INPUTS

In order to characterize the inputs (loading) to the lake, samples were taken on three different occasions (in November and December) at fifteen different points (Figure 2) from the railroad property (well upstream of the lake), at the wastewater treatment plant and the junction of its effluent with the stream from the railroad (mid-point on the stream from the city to the lake), entrance to the lake, and at the spillway and siphon[2] where the water left the lake. A small, nearby lake, Bass Lake, which was unaffected by the oil spill, was also sampled for control purposes.

[1] This diversion box had several small sewers emptying into it and one large one running to the wastewater treatment plant. The sewer to the city's wastewater plant was incapable of handling the flow from incoming sewers during most rainfalls.

[2] In an attempt to withdraw nutrient-laden, oxygen deficient waters from the deeper part of the lake a siphon system was installed. It withdrew water from the deepest part of the lake, assuming it to be the richest in nutrients, and discharged it over the dam (spillway).

SITE NUMBER[a]	DESCRIPTION LOCATION
1	Effluent from lagoon on railroad property
2	Municipal sewer-36" pipe near railroad
3	Stream after effluent from 1 and 2 have mixed
4	Jacob's Creek, prior to inflow from Willard Sewage Plant
5	Small Creek upstream of Wastewater Treatment Plant
6	Willard Wastewater Treatment Plant effluent
7	Jacobs Creek after junction of creek from RR and Wastewater plant effluent
8	Jacobs Creek mouth-at-lake
9	Agricultural ditch
10	Holiday Lake near Jacobs Creek
11	Beach at Holiday Lake
12	East arm of lake (control arm)
13	Lake at spillway
14	Big Bass Lake (control)
15	Siphon outlet

[a] typewritten numbers on Figure

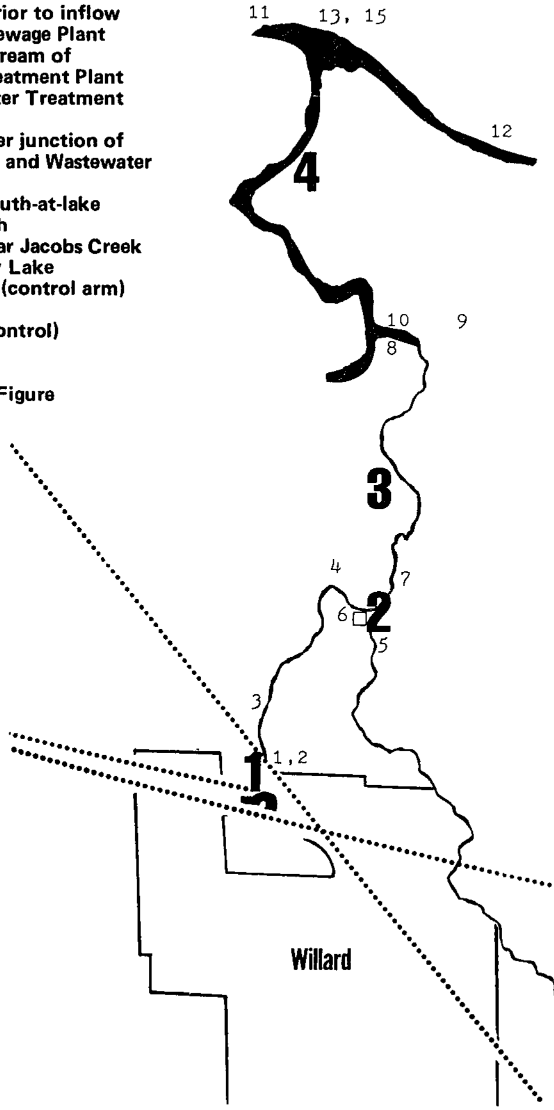

Figure 2. Lake, RR—sampling points

The samples were analyzed, using Standard Methods for pH, specific conductivity, turbidity, oil and grease, solids, (total, suspended, dissolved and volatile), dissolved oxygen, temperature, BOD, COD, nitrate nitrogen and phosphorus [2]. Concentration of key chemical parameters are shown in Table 2. A separate set of samples was taken for microbial analysis, primarily coliform determination; see Table 3 for results.

Other data available to the investigators to aid in characterization of the water quality and loadings include the report by Baker [3].

Table 2. Concentrations of Selected Chemicals

Site Number	*BOD_5*	*COD*	*NO_3^-*	*$PO_4^{\equiv}$*[a]	*Total Solids*	*Oil & Grease*	*DO*[b]
1	83	90	12	1.61	795	42	28
2	75	85	6	7.4	663	18	31
3	75	317	8	2.52	759	11	43
4	70	330	9	2.13	652	11	64
5	6	108	6	1.90	561	7	100
6	27	170	5	16.7	600	4	62
7	26	122	8	17.2	637	8	76
8	15	185	6	11.9	593	6	35
9	13	100	12	11.8	1916	33	86
10	12	100	6	11.6	576	6	30
11	3	158	6	1.57	395	11	83
12	3	115	9	0.96	429	4	98
13	3	85	7	0.98	431	56	115
14	2	108	10	0.37	285	19	83
15	2	–	6	0.60	632	–	<1

Note: Data averaged for three samples except for BOD_5 for which only two analyses were made. All data in mg/l except DO.

[a] Phosphate concentrations reported as $PO_4^{\equiv}$

[b] Dissolved oxygen concentration reported as percent saturation

Table 3. Bacterial Analyses Expressed as Total Coliform Count (Number per 100 ml)

Site Number	*Sample 1*	*Sample 2*	*Sample 3*
1	4,001	63,000	80,000
2	–	750,000	>800,000
3	–	370,000	–
6	750	100	900
7	180	200	–
8	1,800	2,800	>80,000
9	200	600	200
11	2,700	4,100	560
12	10	60	60
13	550	190	–
14	10	10	0

LAKE LOADINGS

To assess the impact of the various inputs on the lake, the measured contaminant concentrations (Table 2) were multiplied by the annual flow rate (Table 1). Data on the loading estimates for the various pollutant inputs in lb/yr are given in Table 4; in Table 5, the loadings are reported relative to each other.

The authors recognized that the average concentrations obtained in these November and December sampling periods in no way represent an annual average. For this reason the loadings are referred to apparent loadings; subsequently in Table 5 relative apparent loadings are reported. Most accurate of the computed loads is that for the wastewater treatment plant, whose annual reports were available. Least accurate were the inputs estimated for runoff, both urban and rural.

The results were revealing but not surprising. As expected, the major inputs were not from the railroad, which contributed much less BOD, suspended solids, oil and nutrients than other sources. In other words, the contribution of the railroad's effluent from their lagoon to the major water quality problems at Holiday Lake was quite small.

Table 4. Summary of Apparent Pollutant Loadings to Holiday Lake

	Loading (lb/yr)			
Pollutant	*Rural*	*Urban Storm*	*Treatment Plant*	*Railroad*
Suspended Solids	3,500,000	222,300	149,000	4,500
BOD_5	53,000	104,150	72,000	9,800
COD	175,000	350,500	N[b]	N[b]
Chlorides	1,050,000	531,000	230,000	7,700
Nitrogen (N)[a]	37,200	21,630	12,600	1,450
Phosphorus (P)[c] A*	3,500	11,700	13,000	65
B**	3,700	5,400	21,000	65

[a] Includes only nitrate nitrogen
[b] Not estimated
[c] Phosphorus Loadings as $PO_4^{\equiv}$
* as estimated in original report by authors
** as revised by Baker [3].

Table 5. Relative Apparent Contribution of Outside Sources to Holiday Lake

Source	*Rural*	*BOD*	*Nitrate*	*Phosphorus*
Railroad Lagoon	1	1	1	1
Agricultural Run-Off	778	5	24	54
Willard Wastewater Treatment Plant	33	7	35	230

Since the parameters which most obviously exceed acceptable pollution levels in Holiday Lake were oxygen (too low) and phosphate (too high), the most significant contaminants of the above are BOD (a measure of the oxygen required to decompose the organic matter present) and phosphorus. Based on those two criteria, it can be concluded that storm runoff and the sewage plant effluents are the major polluters of the lake.

OIL AND GREASE INPUTS

Since the genesis of the lawsuit was an oil spill, coupled with charges that chronic leakage of oil had occurred in the past, special attention was paid to oil and grease concentrations in data gathering and analysis.

Concentrations of oil and grease in aqueous samples were measured by an extraction procedure that yielded combined oil and grease concentrations for both hydrocarbon and non-hydrocarbon oils. Partitioning to determine the relative amounts of each kind of oil was not done. The data analysis included sampling and analysis of oil concentrations of present inputs (railroad wastewater discharge and municipal wastewater treatment plant effluent) plus estimates of loading by urban storm water drainage and notation (but no annualized quantification) of potential inputs from road oiling and motor boats. The loading data for oil inputs are shown in Table 6.

Although the railroad's discharge and oil were synonymous in the minds of the lake residents, the railroad was not the only source of hydrocarbons to the lake. Oils also came from urban areas both through the wastewater plant and combined storm sewer runoff. In northern Philadelphia, PA, oil in runoff from an urban area was estimated by Hunter et al. to be 23 lb/acre/yr [4]. Clearly, Holiday Lake received a significant amount of oil by other than "direct railroad discharge."

Table 6. Estimated Oil and Grease Loadings on Holiday Lake at Time of Study

Source	*Input Rate (lb/yr)*	*Relative Input*
Willard Wastewater Treatment Plant (based on sampling)	20,000	6
Willard Storm Water Overflow (estimate)	1,020,000	222
Railroad Lagoon Effluent (based on sampling[a])	4,600	1

[a] Does not include spill nor amount inputted to the lake prior to the installation of improved oil-removal equipment (i.e., a dissolved air flotation system).

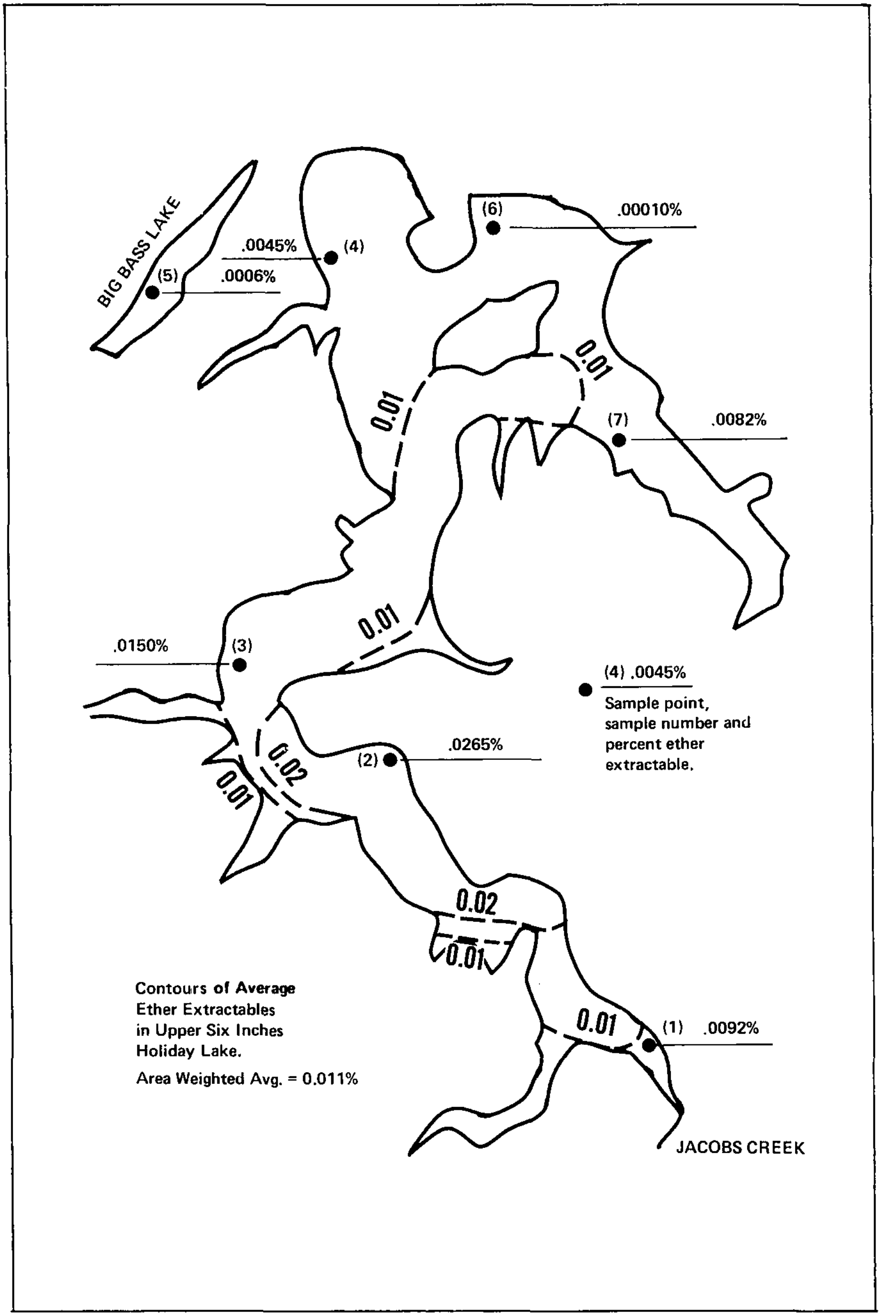

Figure 3. Concentration of oil and sediment of Holiday Lake.

One of the unquantified sources of oil was from the motor boats of the property owners. A study by Rensselaer Polytechnic Institute showed that two-cycle engines exhaust pollutants directly to the water beneath the surface and that, depending on boat density, the water contamination could be significant [5]. Measurements by RPI showed that approximately 401 ml of exhaust products were produced in 30 min of motor operation. Based on these data, and assuming that the exhaust gases contained 85 percent biodegradable carbon, the discharge based on one engine-day is equal to a population of 400 people. The report estimated full wastage from outboards as 100-160 million gallons annually for the 7.1 million outboard motors in existence (160 lb fuel per boat). A conservative estimate of the portion of the fuel which is discharged to the environment would be 10 percent or 16 lb/yr/boat. Since Holidy Lake is heavily used for recreation, it is reasonable to assume a significant amount of oil reaches the lake from outboard engine usage.

In order to determine the significance of the plaintiff's claim that oil had polluted the benthic sediments in the lake, two core samples of the lake bottom were taken at six different locations: one was analyzed chemically and the other visually inspected and the bulk density of the material determined. Three additional cores were collected from Bass Lake, a companion lake that neither experienced the oil spill nor the chronic discharges from either the railroad or the wastewater treatment plant, although it was reported to have received some water pumped from the main lake.

The maximum percentage of petroleum ether extractables in the top 6 in. of the benthos for all six locations in the lake was 0.0265 percent. The area weighted average was 0.011 percent. The data for all sites has been plotted and equal concentration lines drawn in Figure 3. The oil concentration was higher at point 2 where the flow impinged on a beach area. Low levels of oil were found at points 4 and 6, which were out of the mainstream of the flow of water through the lake. As expected, the lowest concentration of benthic oil was found in Bass Lake.

For comparison purposes, these data were compared to samples taken in the Maumee River which flows from an agricultural area through the industrialized city of Toledo (which contains refineries and other oil-discharging industries). The average concentration in the river bottom was 0.67 percent at the mouth of the river (having passed the industrial area), and 0.079 percent at Grand Rapids, Ohio (upstream/agricultural area). Even at the most concentrated position, the concentration of oil in Holiday Lake was one-third of that at Grand Rapids, a point on the Maumee River well upstream of the Toledo metropolitan/industrial area.

STREAM RECOVERY

When raw sewage, treated wastewater and/or any biodegradable organic matter of any type, are discharged into a flowing stream, bacteria flourish due to an influx of food; as a result of the dissolved oxygen (DO) concentration falls due to bacterial respiration consuming oxygen faster than it can be replaced by diffusion from the air. As time (and distance) pass and the food disappears, the number of bacteria decreases and the DO begins to increase (as the respiration rate exceeds the rate of oxygen utilization). The dissolved oxygen concentration data for such a process are correlated as a function of distance and degree of pollution by the well-known Streeter-Phelps equation.

The dissolved oxygen levels in the creek from the railroad property to the lake conformed to the predictions of the Streeter-Phelps equation in two distinct stream reaches. The DO value was low at the railroad outfall; bacteria were high as a result of raw sewage that was discharged by a municipal sewer at the property line. By the time the stream reached the wastewater treatment plant, recovery had begun: DO values had risen and bacterial concentrations had fallen. Resupply of biodegradable material by the treated sewage discharged by Willard (the BOD averaged 47 mg/l) provided new nutrients for growth and by the time the stream reached the lake, the bacterial concentrations had increased and the DO had fallen markedly.

The conclusion reached by the authors was that the original organic material leaving the railroad property was assimilated by bacteria in the stream by the time the water reached the confluence with the effluent from the wastewater treatment plant. However, the stream was unable to use all the organic material supplied by the treated wastewater (and hence recover) before the stream reached the lake.

Two additional points are worthy of note. For an industrial waste from a lagoon[3] that was not an active biological treatment system, the microbial concentrations appeared very high. However, the microorganisms were present in large numbers because the railroad effluent was discharged simultaneously with untreated sanitary waste from a municipal sewer.

Table 7. Profile of Water Quality in Jacobs Creek from Railroad Property to Holiday Lake

	Location on Stream Railroad Property	*Before Waste Treatment Plant Influent Addition*	*At Lake Entrance*
Dissolved Oxygen Concentration (percent of saturation)	43%	62%	35%
Coliform Bacteria (Number per 100 ml)	370,000	600	28,000

[3] The lagoon was simply a holding pond inserted between the dissolved air flotation system and the stream. Presumably, in earlier times, it served to allow free and floating oils to be removed.

At the junction of the creek where the wastewater treatment plant effluent joined the stream from the railroad, the bacterial concentration was low. Few bacteria were present in the chlorinated wastewater. However, chlorination does not preclude growth of new cells if environmental conditions are suitable, which they were between the confluence of the stream and the lake. The residual chlorine disappeared and the nutrients, (BOD, nitrogen and phosphorus) which were contained in the wastewater treatment plant effluent provided ample support for growth (see Table 7).

FATE OF THE OIL

One of the unanswered questions was "where did all the oil go?" No one seems to have seen any of the oil go over the spillway, although some may have. Undoubtedly, some fraction of the spilled oil went into solution and was either discharged from the lake with the overflow or was biologically decomposed. Some oil may have been adsorbed on suspended matter and settled to the bottom of the lake. Some oil, especially the lighter fraction, undoubtedly evaporated.

The authors were unable to determine what fraction of the oil in the sediment was diesel fuel oil from the spill or even which was old diesel fuel oil from chronic discharges in the past. Indeed, it would be very difficult to differentiate between the types of oil that then contaminated the lake bottom–diesel fuel, motor boat oil, oil discharged with the treated municipal wastewater or road oil runoff. All one could say was that oil concentrations, as measured by petroleum ether extraction, amounted to 0.011 percent by weighted oil in the benthal deposits that coated the top 6.0 in. of the lake.

In order to estimate the amount of oil lost to the atmosphere from the spill, a laboratory experiment was performed. Fuel oil (of the type spilled) was placed in uncovered, weighted dishes; the evaporative weight loss was monitored as a function of time. At 20°C, in three days, 27 percent of the oil evaporated; in six days, a 40 percent weight loss was measured. These evaporation rates can only be considered as the lower boundary limit because wind and wave action will accelerate the evaporation rate. Extrapolation of these conservative laboratory results yielded an evaporation rate of 430 gal oil/acre of lake surface/day. Compare these results to the approximately 4000 gallons of oil lost to the lake in the spill.

The foregoing discussion does not try to make a case for total disappearance of the oil by evaporation, although a significant amount must have gone this route. Certainly a major fraction of the oil dissolved into and was transported both vertically and horizontally by the water column. However, equally certain is the disappearance of a major fraction of the oil through evaporation. It is believed that only a small fraction of the actual spill made its way to the bottom of the lake. The major fraction of benthic oil is probably from prior industrial and municipal inputs. This conclusion is supported by the distribution of oil within the upper 6.0 in. of the benthic cores.

EUTROPHICATION

While all natural, as well as man-made lakes, undergo eutrophication, the rate can be slow or fast depending upon external factors. For man-made lakes, it is not uncommon to find a relatively new lake in an advanced stage of eutrophication. Small lakes are particularly susceptible to accelerated eutrophication through loadings of wastewater high in nutrients.

The undesirable consequences of eutrophication are: 1) depletion of dissolved oxygen, 2) increased turbidity of the water, 3) accumulation of organic matter (benthic deposits), and 4) nuisance blooms of algae. Secondary effects are the elimination of beneficial bottom organisms such as the mayfly larvae (*Hexagenia* and others) that are essential in the diet of certain valuable fish. Eutrophic lakes will also show an increase in low-oxygen tolerant forms of life such as sludge worms (*Tubifex*) and midge larvae (*Chironomous*).

Boughey describes four features for detection of eutrophication [6]:

1. Increased amounts of standing crop
2. Diminished transparency
3. Lower oxygen production
4. Higher nutrient levels

Baker noted that excessive growths of algae have plagued Holiday Lake for many years [3]. He reported that blooms often reached massive proportions and adversely affected the recreational use of the lake. These blooms are believed to be caused by the wastewater treatment plant effluent. Increasing evidence indicates that algae levels in lakes are controlled by the external input of nutrients. Indeed, Jones and Backmann have found a linear correlation between chlorophyll and phosphorus for 143 lakes [7].

Concentrations of nutrients in Holiday Lake were high. The authors' data (three samples only) indicated phosphorus levels of 1.57 mg/l, as PO_4 and nitrate levels of 6 mg/l at the beach. At the spillway where the lake drained, the phosphorus was 0.96 mg/l. The phosphorus level was much higher near the lake entrance where it was 11.6 mg/l PO_4 due to the creek inflow. Baker's data reported on twenty-two samples [3]. He reported average phosphate concentrations of 2.1 mg/l in the hypolimnion and 0.56 mg/l in the epilimnion. A conclusion of Baker's study was that significant amounts of phosphorus are accumulating in the lake. The authors concur—with 11.6 mg/l PO_4 at the main creek entering the lake and 0.96 mg/l at the exit, there must have been significant precipitation of phosphates between these two points.

According to a study by the National Academy of Sciences, threshold levels of nutrients are: nitrates 0.9 mg/l, as nitrogen, and 0.1 mg/l soluble orthophosphate as P [8]. Beyond these concentrations, eutrophication problems will develop. Holiday Lake was enriched an order of magnitude beyond the threshold levels specified by the Academy.

Vollenweider suggested that a lake would be in danger with regard to its trophic level if springtime concentrations of assimilable phosphorus compounds exceeded 0.01 mg/l, and/or if the annual loading was greater than 0.13-202 gP/m^2yr; for the required companion nutrient, inorganic nitrogen, the comparable values were 0.2-0.3 mg/l and a loading of 2-3 gN/m^2yr [9]. From the data in Table 4, one can calculate the relevant loadings to be 15 (P) and 30 (N) g/m^2yr. It is obvious that both concentration and loading values are far in excess of the required level for nitrogen and phosphorus to produce noxious algal conditions.

Of significance, Larsen and Malueg utilized the above data in a study of Shagawa Lake, MN whose eutrophication level and loadings parallel Holiday Lake [10]. The major source of nutrient to Shagawa Lake (about 2200 acres in size) was the treated wastewater (secondary biological) of Ely, MN (population 500). The lake was clearly eutrophic, even at a phosphorus concentration of 0.025-0.1 mg/l. In mid-summer near anoxic conditions existed in deeper (mean depth 17 ft) waters.

The only conclusion that can be drawn from the foregoing discussion is that Holiday Lake is highly eutrophic with nutrients in the influent being the major cause. The net result was massive algal blooms, resulting in reduced recreational potential, high turbidity and increased benthic deposits that required expensive dredging. Thus the lake did have major ecological problems before the spill and will continue to have major ecological problems after the oil spill.

DISCUSSION

It is evident from the data, especially the loading tables, that Holiday Lake has many problems. The oil spill certainly was an insult to the lake, already in trouble because of its major water source, but no intermediate or long term injury resulted from the spill.

Unfortunately Holiday Lake has been in ecological trouble since its construction. Algal blooms have long been a problem. Algae proliferated as a result of the abundant nutrients in the main water flow because of high concentration of biodegradable organics, nitrogen and phosphates. Unaesthetic, and foul-smelling, the algae proliferated. The result of photosynthetic activity was the production of further biomass which is potentially a source of biodegradable carbonaceous material greater than the original pollutants [11]. Blooms hindered recreation and led to substantial benthic deposits when the algae died and sank.

Most important to lake residents were swimming and water skiing. Yet even in late fall (October and November) the coliform bacterial counts were much higher than allowable for bathing (see Table 3). State of Ohio criteria for bathing areas are: Coliforms–monthly average 1000/100 ml, with a maximum of 2400 for any one sample. McGaughey utilizes a more restrictive standard to recommend water for use for bathing and fish life [12]. He suggests the coliform count be between 50-100/100 ml, BOD_5 1.5 mg/l on the average with no sample above 3.0 mg/l, a DO average better than 6.5 with no sample less than 5.0 mg/l. Thus, the lake is unsuitable, even in late fall, for water contact, a condition not at all attributable to the railroad and either its chronic or accidental discharges.

The high concentration of bacteria leads to the conclusion that the water is not suitable for body-contact recreation, nor could it be expected to be with much of the flow coming from a municipal wastewater treatment plant. Even though the wastewater treatment plant is a well-designed and well-operated secondary (trickling filter) biological plant, the water discharged from such a plant is not suitable, without further treatment for direct recreational use.

Sophisticated techniques of water renovation must follow secondary treatment before the water can be reused. An example of this type of treatment is found in California, at Santee [13]; recreational facilities are being designed to reuse treated wastewater, but after further extensive treatment of biological effluent, first in an oxidation pond where the effluent from a secondary, biological wastewater treatment plant is retained for thirty days therefore being allowed to percolate through a natural soil sand bed. The effluent from this process is chlorinated before being discharged into a swimming area. Coliform counts for the effluent from the swim area of the lake averaged 2/100 ml.

CONCLUSIONS

1. The oil spill had a short term impact on the lake resulting in:
   (a) an unaesthetic covering of surface, boats, inlets, shoreline, etc. with diesel fuel oil
   (b) benthic damage occurred
2. The biological impact of the spill on fish and waterfowl was not determinable.
3. The long term impact of the spill and other inputs appears limited to oil concentrations in the sediment of less than 0.03 percent by weight. The deleterious effect of these concentrations in the bottom deposits was not demonstrated.
4. Significant amounts of oil were added to the lake by motorboats, by urban runoff and by the wastewater treatment plant effluent.
5. Over one-half the time, one-half of the flow into the lake is treated municipal sewage.
6. The water quality in the lake is poor, especially where water contact sports are considered; by comparison to water quality criteria, the lake is deemed unacceptable for recreational use.

7. Nutrients are abundant. Phosphorus and nitrogen are supplied in large amounts by the municipal effluent as well as urban and agricultural runoff.
8. Phosphorus is accumulating in the lake bottom.
9. Algal blooms are frequent. Algae are not only unaesthetic but eventually add considerable carbonaceous organic matter to the benthos.
10. Due to algal blooms, the benthic deposit rate in the lake is extremely high, causing dredging to be done periodically; dredging can be very destructive to the benthic ecology.

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