# LAKE ONALASKA REHABILITATION FEASIBILITY STUDY

Submitted to: The Lake Onalaska Rehabilitation District

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Submitted by: The River Studies Center

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# Acknowledgements

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# Statement of Objectives

The objectives of this study are to:

1. Assess the eutrophic state of Lake Onalaska since its creation in 1937.
2. Assess the rate of sedimentation in the lake since its formation.
3. Assess the standing crop and distribution of rooted aquatic macrophytes in the lake.
4. Construct a one-foot contour map of the lake.
5. Provide recommendations regarding possible renewal or reclamation procedures, that are ecologically sound.

# INTRODUCTION

During the 1930s, 29 locks and dams were constructed on the Upper Mississippi River between St. Louis and St. Paul, Minnesota, to provide navigable depth for nine-foot draft commercial vessels. The placement of these dams transformed the free-flowing river into a series of shallow, low-storage pools. Locks and Dam No. 7, located at Dresbach, Minnesota, supports an eight-foot head reservoir extending approximately 14 miles upstream, to Trempeleau, Wisconsin. Pool 7, consisting of approximately 12,500 acres of water, can be divided into three portions with regard to general habitat type: the upper approximate one-third of the pool consists generally of active channels carrying water from and parallel to the main channel; the middle one-third of the pool consists of flooded marsh with numerous small potholes, many of which are isolated from the main channel and therefore from a fresh water supply. The lower one-third of the pool consists of Lake Onalaska, an inundated floodplain meadow.

Prior to closure of the dam, the area now occupied by Lake Onalaska was primarily meadow, with interspersed stands of mature floodplain forest, consisting primarily of cottonwood and willow. The area was utilized by a small number of farmers, primarily for the production of hay. Just prior to closure of the dam, the trees were cleared from all areas that would ultimately be flooded, leaving only the stumps. The lake was formed in 1937 upon completion of the dike works.

The Black River, draining a small portion of west-central Wisconsin (primarily low, wet deciduous forest) has its confluence with the Mississippi River approximately seven miles upstream from Lock and Dam No. 7. It forms a large delta and the river itself is divided into several channels that are presently braided in this vegetated delta. The discharge of water from the Black River is subsequently diffused as it enters the Mississippi River. Originally, the main confluence with the Mississippi was located two miles downstream from the present location of Lock and Dam No. 7, just above the mouth of the LaCrosse River. However, the closure of the dam inundated four miles of the original Black River channel. Consequently an additional dam and spillway were constructed in the old channel to assist in supporting the pool (the Onalaska Spillway). The result was the formation of a lake that receives water from two primary sources: the Mississippi River through several channels leading from the main channel and the Black River. In addition to this, water is also supplied to the lake from Halfway Creek, albeit an insignificant discharge at normal runoff rates.

## DESCRIPTION OF THE STUDY AREA

Lake Onalaska proper consists of 5,400 acres of open water with two large islands located in the eastern portion and one elongated island centrally located in the southern part of the main lake (see map). It is bounded on the riverine side by a chain of barrier islands that physically separate it from the main channel of the Mississippi River. Water flow between these islands occurs at nine locations. The mean depth of the lake is five feet, and the bottom of the main portion of the lake contains little contour detail. A few deep holes are present in the lake and reflect artificial modifications due to dredging (see map). The deep hole adjacent to the airport runway is a borrow pit for fill for the construction of the runway. The deep holes immediately upstream from the dike-work are a result of the same activity for the construction of the dike. The extremely deep hole in the lower opening of the lake leading back to the main channel is formed by scour, as this opening carries the majority of the water flowing from the lake back to the main channel of the river.

The sediment type in the lake ranges from medium sand to organic muck. Where muck prevails, it is always associated with the growth of rooted aquatic macrophytes, these being the source of the organic material. The vast majority of the upper and central portions of the lake have a firm, sandy bottom. The clay-size sediments in this area are constantly re-suspended by wave action and are subsequently carried to the wind-protected portions of the lake. Where organic sediments prevail, they are always superimposed on a layer of medium sand. Organic layers range from six inches to three feet in depth in the extremely eutrophic portions of the lake.

Because the lake does not thermally stratify under normal conditions, the water chemistry characteristics are quite similar to those in the river proper. Generally temperatures in the lake fluctuate annually between zero and approximately 30°C. Dissolved oxygen concentrations vary in the lake, fluctuating between near zero to 13 mg/L in the vegetation beds but remaining relatively high in the open portions of the lake. The pH remains quite stable throughout the year with an annual average of 7.42. The alkalinity is similar to that found in the river with an annual average of approximately 125 mg/L. Nutrient analyses in vegetation beds reveal that available nutrients are accumulating in the lake and that transport from the lake probably does not equal production (this will be discussed in a later section of this report). The water is colored by the refractory organic materials that are introduced by the Mississippi and Black rivers. Average annual color values approximate 35 PtCo units.

The watershed of the lake can be considered to be the same as that of the Upper Mississippi River above Lock and Dam 7.

Portions of the shoreline of the lake are inhabited by permanent residences. Brice Prairie, which bounds the lake on the northeast, is completely subdivided for a distance of three miles. Whereas the elevation of these dwellings is high (8 to 28 feet above normal pool), it is presumed that the individual septic systems leach into or are intermittently pumped into the lake. This nutrient input, however, is probably insignificant when compared to the total nutrient budget. The western shore of French Island is also inhabited on its entire length. Here, however, the lots are larger, and the sewage is carried to the municipal treatment plant. There is little input to the lake from these sources.

The capacity-inflow ratio of the lake is quite high due to the lateral location of the lake to the river; therefore, the trapping efficiency of the lake for sediments is high (between 55% and 60% of the suspended load and 100% of the bedload). During the past 40 years this has resulted in an alarming loss of depth which exceeds 50% in some of the areas of the pool adjacent to the barrier islands that separate from the main channel.

In summary, the lake is a shallow basin lying lateral to the main channel of the river. It has a high capacity to support the growth of rooted vegetation, and it has a high trap efficiency. Later discussion in this report will reveal that it is progressing toward hyper-eutrophy at a rapid rate and will undergo drastic changes in the next 30 to 40 years. The lake is accumulating nutrients which stimulate the encroachment of vegetation into the now open-water areas. There is no significant input of nutrients from the relatively small number of lakeshore dwellings. The ratio of watershed area to lake surface area is extremely high because of its location on the Mississippi River.

## METHODS AND MATERIALS

### Mapping

Baselines and control points were established around the perimeter of the lake and on islands where visible landmarks could be recognized. East-west transects were established at 50-foot intervals from the dike-work to the upper reaches of the pool. Additional north-south transects were established in the pool to cross-check the depth determinations that were made on the east-west transects. A total of 450 transects were run and cross-checked.

All depth determinations were made with a Raytheon De 719B survey fathometer mounted in an air-boat. Directional control of the vessel was accomplished by sighting the transect with an alidade and communicating direction to the boat via two-way radio. A continuous recording was made for each transect. Finite values were taken from the continuous trace and were transferred to a control map. Contours were constructed on the basis of approximately 4,000 values on the control map. One-foot contours were constructed for the entire pool except in the deepest portions of the pool where physical constraints did not allow for the placement of all contours. All values were corrected for control pool elevation at 638 feet msl.

## MACROPHYTE-NUTRIENT RELATIONSHIPS

Field sampling was initiated on November 3, 1975 and continued through November 13, 1976. Samples of water, sediments, and plants were obtained from all previously described Lake Onalaska stations at each sample time. Fall and spring sampling (September-November, March-May) occurred at two-week intervals, winter sampling (December-February) at three-week intervals and summer sampling (June-August) every nine days.

A hypothetical grid was established at each site, allowing previously undisturbed samples to be obtained. Samples were taken from each site in the order of water, sediments, and plants. This order was maintained so that sediment disruption, when coring, would not alter nutrient concentrations in water samples.

### WATER

Collection: Water samples were collected with a two-liter Kemmerer water sampler at mid-depth in the water column. At times of low water, samples were collected at mid-depth in sample bottles. The sample was transferred to a one-liter polyethylene bottle. Sample water was also placed into a 300ml glass-stoppered bottle. Chemical analyses were performed on the water from the polyethylene bottle, and dissolved oxygen was determined in the 30-ml bottle.

All sample bottles were acid washed and rinsed with deionized water in the laboratory. Prior to collection, each bottle was rinsed with lake water from the corresponding sample site.

## Field Methods

Depth and Current Velocity: Water depth was determined at each sample site using a standard meter stick.

Current velocity was determined periodically throughout the year using a Price-Simpson current meter. Measurements were made deep enough to avoid any influence of the boat.

Temperature: Temperature determinations were made at mid-depth in the water column with a -10 to 100°C mercury thermometer.

Dissolved Oxygen: The dissolved oxygen content of the water was determined using the Azide modification of the Winkler Method (American Public Health Association, 1975). Samples were fixed in the field, water sealed, and kept in the dark until analysis could be completed in the laboratory.

## Laboratory Methods

Sample Preparation: Six hundred milliliters of the collected water were vacuum filtered through prewashed Gelman$^R$ glass fiber filters. This water was used for the analysis of the following nutrients: soluble inorganic phosphate phosporus, nitrate nitrogen, nitrite nitrogen and soluble Kjeldahl nitrogen. Total phosphorus, pH, and alkalinity were determined from the remaining unfiltered sample.

pH: The hydrogen ion concentration, as pH, was determined electrometrically with an Orion$^R$ digital pH meter, model 701, and a Corning$^R$ combination electrode (APHA 1975).

Alkalinity: A potentiometric titration of the water sample with 0.02N $H_2SO_4$ was employed to determine total alkalinity (APHA 1975). The pH endpoint was determined by temperature and total carbonic species present as the bicarbonate ion. Alkalinity is expressed as meq/L.

Phosphorus: Soluble inorganic phosphate phosphorus ($PO_4$-P) was analyzed using the single reagent method of the Environmental Protection Agency (1974). The persulfate digestion procedure (EPA 1974) was employed to determine the total phosphorus content of the water. Total phosphorus is the sum of particulate, dissolved organic and dissolved inorganic phosphorus. Combined phosphorus was then calculated as the difference between the total and inorganic phosphorus. Dissolved inorganic phosphorus is reported as mg $PO_4$-P/L and total phosphorus as mg P/L.

Nitrogen: Nitrogen as nitrate ($NO_3$-N) was determined by the method of Mullin and Riley as described by Barnes (1959). The phenoldisulfonic acid method (APHA, 1965) was initially employed for $NO_3$-N determinations. It was abandoned due to a lack of accuracy and precision. The Mullin and Riley method proved very satisfactory. Nitrogen as nitrite ($NO_2$-N) was analyzed using the buffer color reagent of the EPA (1974) and is reported as mg $NO_2$-N/L. The macro-Kjeldahl technique of the EPA (1974) was employed to determine soluble Kjeldahl nitrogen. A colorimetric analysis was performed on duplicate samples using Nessler reagent. The results are reported as the average of the duplicates in mg soluble Kjeldahl nitrogen/L.

Soluble Kjeldahl nitrogen is defined as the sum of soluble free ammonia and organic nitrogen compounds.

## SEDIMENTS

Collection: Sediment samples were obtained from each sample site using a simple coring device constructed of polyvinylchloride. The corer was a cylinder, 183 cm in length and 5 cm in diameter. Two cores, taken to a depth of at least 25 cm, were obtained from each site at all sample times. Each core was immediately separated in five-centimeter sections, with the sediment-water interface as the starting point. A sediment sample from each site, therefore, consisted of two cores separated into section of 0-5 cm, 5-10 cm, 10-15 cm, 15-20 cm and 20-25 cm. Corresponding sections of the two cores were then placed into sterilized whirlpacks$^{R}$.

Lee (1970) indicated that the mixing, or active zone, of the sediments generally extended to a depth of 5 to 10 cm below the sediment-water interface. More specifically, Keeney (1972) has shown that nitrogen in sediments is active to a depth of 20 cm; and Sridharan (1970) has demonstrated that phosphorus is active down to 15 cm. Each core was therefore taken to a depth of at least 25 cm to include the active zones of nitrogen and phosphorus.

Samples were held in a deep freeze, -4°C, until analyses could be performed. The water-logged consistency of the sediments precluded denitrification (Hesse 1971), and the freezing temperatures halted microbial degradiation of the sample.

## Laboratory Methods

Sample preparation: Samples were dried at 106°C (APHA 1975), and ground with a porcelain mortar and pestle to pass a 60 mesh sieve (Jackson 1958). Total Kjeldahl nitrogen was determined using 0.5 to 2.0 g of the dried sediment. Available sediment nutrients were simultaneously extracted from 2.0 g of sediment by continual agitation for 30 minutes with 225 ml of deionized water (Olsen 1965 and Thomas and Peaslee 1973). Nutrients included soluble orthophosphate phosphorus, nitrate nitrogen, and nitrite nitrogen. The extraction water was then vacuum filtered through prewashed Gelman$^{R}$ glass fiber filters. Analyses were preformed on the filtrate.

Analysis of water soluble phosphorus and nitrogen, that is P and N extracted with water, give a quantitative, accurate account of the nutrients that are readily available to plants. Thomas and Peaslee (1973) indicate that water soluble P is the best estimate of P that is available to plants. Olsen (1965) also indicates that water soluble P is an index of phosphorus availability. Nitrogen, as nitrate and nitrite, can also be determined quantitatively with water as the extractant (Bremner 1965).

Phosphorus: Available phosphorus as $PO_4$-P was determined on the extractant filtrate using the single reagent method of the EPA (1974). Results are expressed as ug $PO_4$-P/g sediment.

Nitrogen: Total Kjeldahl nitrogen (TKN) was determined by the macro-Kjeldahl method as outlined by Bremner (1965), Jackson (1958) and the EPA (1974). Samples were run in triplicate through July and then in duplicate. Precision and accuracy precluded the need to run triplicate samples. TKN is the sum of organic N plus ammonia. Final concentrations are expressed as the average of all determinations in mg TKN/g sediment.

Available nitrogen, as $NO_3$-N and $NO_2$-N, was determined using the same methods described previously under water laboratory methods. Results are expressed as ug $NO_3$-N/g sediment and ug $NO_2$-N/g sediment.

## MACROPHYTES

Collection: Plant samples were collected at the *Ceratophyllum demersum* and *Nymphaea tuberosa* site each sampling time. The sampler was an aluminum enclosure 0.5 m on a side and 0.5 m high; the total area was 0.25 $m^2$. During ice cover a cylindrical, aluminum sampler with an area of 0.13 $m^2$ was employed. A sample of 0.25$m^2$ was taken each time at each site. The aluminum enclosure type of sampler was chosen because it definitely demarked the 0.25 $m^2$ area through the volume of water, and samples could be taken from the boat (Sefton 1976).

Samples were taken within the appropriate grid area. However, the sampler was randomly thrown into the water. It was pushed into the sediments, cutting off any material not falling within the quadrant (Sefton 1976). Vegetation, including underground parts, was removed by means of a four pronged rake.

Samples were placed in black polyethylene bags and stored in the shade until transported to the laboratory.

## Laboratory Methods

Sample preparation: Upon arrival to the lab, the plant material was washed by hand with a high velocity jet of water. Washing effectively removed soil, epiphytes, and animals (Westlake 1969). Plants were initially dried at room temperature (Gerloff 1966). *Ceratophyllum demersum* and *Nymphaea tuberosa* were then separated according to plant parts, dried in a forced-draft oven at 60-70°C (Gerloff 1966, Chapman and Pratt 1961), biomass determined, and then stored in a deep freeze at -4.0°C until analyzed (Westlake 1969). Just prior to analysis, the plant parts were ground with a porcelain mortar and pestle to pass a 40-mesh screen (Jackson 1958). Total phosphorus and total nitrogen were determined from these samples.

Biomass: Biomass of *Nymphaea tuberosa* and *Ceratophyllum demersum* was determined. Total biomass of each plant was calculated, as well as the individual biomass of its rhizome, petiole, leaf, and flower. All other macrophytes present were weighed and identified with Fassett (1975) or Carlson and Moyle (1975). Biomass is reported as g dry weight/$m^2$.

Phosphorus: Total phosphorus was determined using the ammonium persulfate method of the EPA (1974). Sample size ranged from 1.0 to 2.0 g of dried tissue. Samples were run in duplicate with results expressed as the average in mg P/g tissue.

Nitrogen: Nitrogen is absorbed mainly as nitrate (Epstein 1972) and is reduced and incorporated in organic components within the plant (Bandurski 1965, In Bonner and Varner). A determination of nitrate and organic nitrogen would, therefore, yeild an accurate account of the total N within the plant tissue. A macro-Kjeldahl technique modified to include nitrate nitrogen was employed to determine total nitrogen (Jackson 1958). Sample size ranged from 0.5 to 1.0 g of dried plant tissue. All samples were run in duplicate or triplicate. Results are expressed as mg N/g tissue.

Colorimetric determinations of water, sediments, and plants were performed on a Bausch and Lomb Spectronic 20. Glassware for all analyses was acid washed, rinsed with deionized water, and stoppered when not in use (Stickland and Parsons 1968).

## DATA ANALYSIS

Nutrient concentrations of the sediments, water column, and plant material were converted to a common unit of mg nutrient/$m^2$ by the following equations:

$$\text{sediment nutrients} = \text{mg nutrient}/m^2 = \frac{\text{mg nutrient}}{\text{g sediment}} \cdot \frac{\text{g sediment}}{m^2}$$

$$\text{water nutrients} = \text{mg nutrient}/m^2 = \frac{\text{mg nutrient}}{L} \cdot \frac{1000L}{m^3} \cdot \frac{\text{depth (m)}}{1}$$

$$\text{plant nutrients} = \text{mg nutrient}/m^2 = \frac{\text{mg nutrient}}{\text{g plant}} \cdot \frac{\text{g plant}}{m^2}$$

This data was then used to determine concentrations and correlations of nutrients in their respective compartments (sediment, water, plant).

Nutrients absorbed or lost per day were determined for sediments, water, and plants following the general idea of Boyd (1969).

$$\text{mg nutrient gained or lost/m}^2\text{/day} = \frac{\Delta N}{\Delta t}$$

where: $\Delta N$ = change in nutrient concentration during the period $t_2 - t_1$

$\Delta t$ = number of days between $t_1$ and $t_2$.

By observing changes in nutrient concentrations of the sediments, water, and plants, movement of the nutrients from one compartment to another can be determined.

Net productivity was calculated from the expression (after Chapman 1969):

$$\text{Net productivity g/m}^2\text{/day} = \frac{Pn}{\Delta t}$$

where: $Pn$ = net production ($g/m^2$)

$\Delta t$ = number of days between $t_1$ and $t_2$.

The difference between means of the nutrients in the control, and the experimental sites were calculated to determine whether significant differences occurred between the sediment and water concentrations of nutrients. The basic t-test was employed (Downey and Heath 1970).

## Sedimentation Rates

The sedimentation rates for various portions of the pool were calculated by locating 1,100 points in the pool and comparing the elevation of these points to those that were determined for the same locations prior to the construction of the dam (USACE, 1927). The 1927 values were subtracted from the corrected 1976 values and the differences were expressed as loss of depth. Rates were calculated by dividing the difference by the 39 years of existence of the lake.

# RESULTS AND DISCUSSION

## Mapping

A one-foot interval contour map is provided for Lake Onalaska (attached). By looking at the map, one can conclude that the majority of the lake lacks contour detail. This is particularly true for the upper reaches of the main portion of the lake because of wind action which is responsible for the transport of bedload and saltitorial load in these areas. The eastern portion of the lake (east of Bell and Rosebud islands) is quite shallow and supports rooted vegetation in the upper portion. The inundated Black River channel is still visible, although much detail has been lost since closure of the dam.

This general lack of detail in the bottom contour is not surprising since the configuration of the lake in a northwest-southeast direction provides a four mile wind fetch for the predominant northwest winds during spring and autumn.

## Sedimentation Rates

The lake was divided into eight sectors for the analyses of sedimentation rates (Figure 1). The sectors were established on the basis of their similarity with regard to loss of depth.

Area 1, located immediately upstream from the dike-work, experienced an increase in mean depth, due to the fact that it was a borrow area for material to construct the earthen dike. The total area had an increase of 18% total volume

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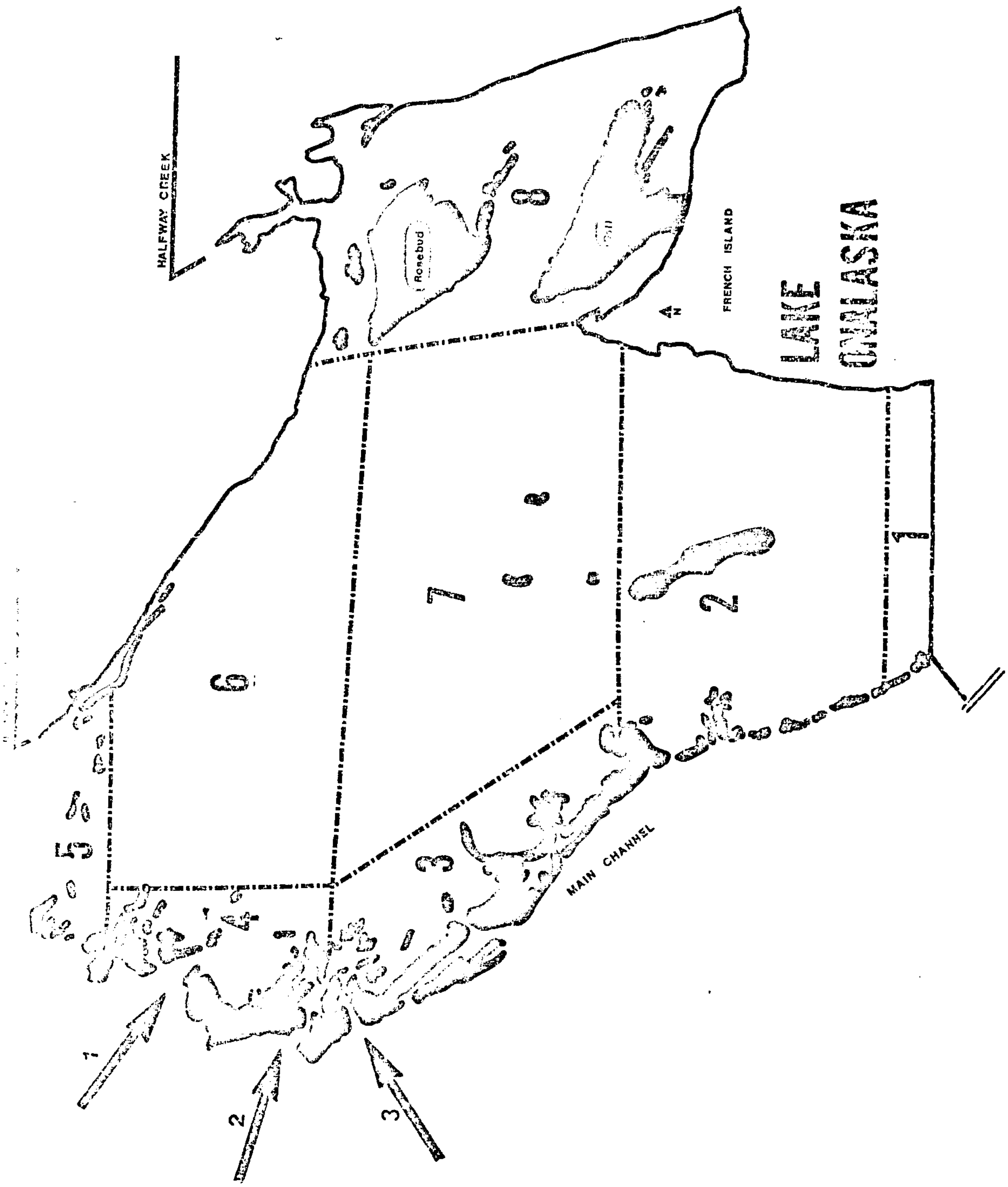


(Table 1) although this datum is probably not ecologically significant.

Area 2, located immediately upstream from Area 1 is somewhat protected from wind action due to the constriction of the lake at this point and to the position of Red Oak Ridge, a prominent island in the lower portion of the lake (Figure 1). Because this area is isolated from the inflow of water from the Mississippi River and in fact contains several outlets to the river, the transport of sediment into this area was the lowest of all areas (except Area 1), which demonstrates a 20% loss in the 39 years since construction. Presumably, the incoming sediments are transported into Area 2 due to re-suspension by traveling surface waves in the upstream areas.

Area 3, located just west and adjacent to the lower barrier islands, has lost 40% of its volume since the construction of the dam. This is undoubtedly due to the transport of bedload through the active feeder channels located on the riverine side of this area.

Areas 4, located immediately upstream from Area 3, demonstrated the same phenomena although to a lesser degree (34% loss) (Figure 1, Table 1).

Area 5, located at the upstream-most portion of the lake, also receives water from the Mississippi River during normal flow. However, during periods of flood, most of the barrier islands separating this area from the Mississippi River are over-topped, and large volumes of suspended and bed load

Table 1. Sedimentation rates (averages for areas and for total lake) and percent loss of depth from 1938-1976, Lake Onalaska, 1976.

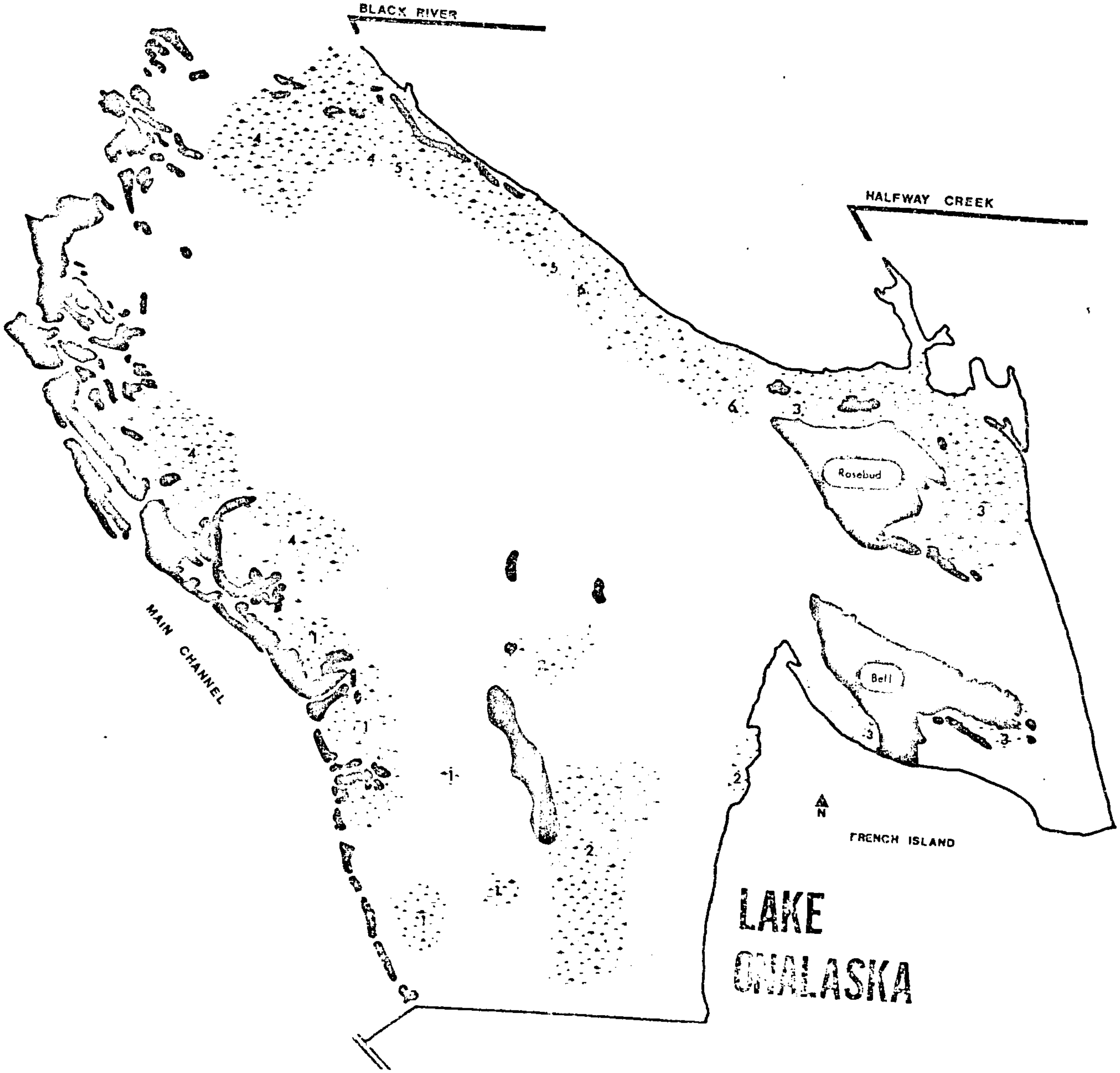
| AREA | 1938 depth (ft) (calculated) | 1976 depth (ft) | Difference | Sed Rate (in./yr) | % Loss |
|---|---|---|---|---|---|
| 1 | 3.69 | 4.5 | -0.81* | -0.27 | -18% |
| 2 | 5.65 | 4.5 | 1.15 | 0.384 | 20% |
| 3 | 6.63 | 3.4 | 3.23 | 1.076 | 49% |
| 4 | 5.52 | 3.7 | 1.82 | 0.606 | 34% |
| 5 | 5.30 | 2.6 | 2.70 | 0.899 | 50% |
| 6 | 6.96 | 5.0 | 1.96 | 0.654 | 28% |
| 7 | 6.85 | 5.0 | 1.85 | 0.615 | 26% |
| 8 | 4.88 | 3.0 | 1.88 | 0.627 | 38% |

*Due to dredging during construction of earthern dam.

material are transported into this area (Table 1). A loss of 50% of the original volume has been experienced since closure of the dam.

Areas 6 and 7 collectively constitute the largest portion of the lake and constitute virtually all of the open water in the upstream two-thirds of the lake. The loss of volume in these two areas since 1937 is 28% and 26%, respectively. This similarity is not surprising since the sediment material that enters between the barrier islands is re-suspended by traveling surface-wave activity and becomes rather evenly redistributed in the main open portion of the lake. An examination of the contour map supports this, as there is virtually no detail in these areas.

Area 8, constituting the eastern portion of the lake, has experienced a 38% loss of volume in the 39 years of existence. The rate of filling in this area is probably related to the stands of rooted aquatic vegetation that have existed there for many years. This was one of the few areas in the lake basin that was capable of supporting vegetation immediately after closure of the dam. The loss of depth due to allochthonous sediments was no doubt accelerated by the continual addition of organic material arising from the high annual production of macrophytes. The existence of macrophytes also served as more efficient trap for any sediments that were introduced from the watershed. Although no data are available for sediment transport from Halfway Creek, it is highly probable that at least during periods of flooding,


BLACK RIVER
HALFWAY CREEK
Rosebud
Bell
FRENCH ISLAND
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MAIN CHANNEL
LAKE
ONALASKA
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the suspended load and bedload from this tributary is significant. Halfway Creek has an extremely unstable bed material and supports virtually no benthic organisms. During periods of normal flow, however, no significant sediment input from this tributary has been observed.

By averaging the loss of depth for all areas and correcting for the size of the areas, one can conclude that the lake has experienced a loss of approximately 31% of its original volume since the closure of the dam.

## Rooted Aquatic Macrophytes

The June-July standing crops of rooted aquatic macrophytes were measured in all areas of the pools, and beds of vegetation that existed at that time were grouped on the basis of similarities of species composition and standing crop. Figure 2 shows the distribution of macrophytes that occur in densities equal to or greater than 80 plants/m$^2$. It must be noted that rooted plants were observed throughout the entire pool at various concentrations less than that stated. However, the size and location of the major beds are shown in this figure.

Areas 1 (Figure 2), situated in the lower reaches of the lake adjacent to the barrier islands, had an average biomass of 149.22 gm/m$^2$. The most frequently collected species was *Ceratophyllum demersum* (F = 0.53) followed by *Elodea canadensis*, and *Potamogeton crispus*. *P. crispus* accounted for almost one-half of the total biomass in these beds, however (Table 2). A total of 12 species were collected in these areas.

Table 2. Rooted aquatic macrophyte species, frequency of occurrence, biomass, and total biomass of all species, Area 1, Lake Onalaska, 1976.

| SPECIES | F | AVERAGE BIOMASS (gm/m$^2$) |
|---|---|---|
| *Ceratophyllum demersum* | .53 | 15.94 |
| *Elodea canadensis* | .43 | 4.98 |
| *Potamogeton crispus* | .40 | 73.45 |
| *Lemna trisulca* | .33 | 13.72 |
| *Heteranthera dubia* | .30 | .73 |
| *Vallisneria americana* | .23 | .73 |
| *Potamogeton foliosus* | .13 | 1.13 |
| *Myriophyllum spicatum* | .13 | 1.05 |
| *Nymphaea tuberosa* | .13 | .07 |
| *Potamogeton pectinatus* | .10 | 15.85 |
| *Lemna minor* | .03 | .07 |
| *Potamogeton zosteriformis* | .03 | .013 |
| TOTAL | | 149.22 |

In area 2, (lower portion of the lake, associated with Red Oak Ridge) (Figure 2), the most frequently collected species was *P. crispus* (F = .53). It comprised more than one-half of the total biomass (Table 3). The filamentous alga (*Cladophora spp.*) was also predominant, as it grew in masses that became entangled in the rooted species existent there and comprised approximately one-fourth of the total biomass. The total biomass of macrophytes and *Cladophora spp.* in this area was 100.4 gm/m$^2$ (Table 3).

Areas 3 were defined as those vegetation beds that were associated with Rosebud and Bell islands. Virtually all of these beds have been established for at least 20 years and probably longer. The constant accumulation of organic material in this portion of the lake has provided for the growth of extremely dense standing crops of vegetation (Figure 2). The average total standing crop in these beds was 591 mg/m$^2$ (Table 4). *Sagittaria latifolia* comprised one-third of the total standing crop (194.8 gm/m$^2$) and was collected in approximately one-third of the samples. The most frequently collected species was *Lemna minor*, the floating duckweed. In these beds, several species made significant contributions to the total biomass; *L. minor*, *Ceratophyllum demersum*, *Elodea canadensis*, *S. latifolia*, *S. rigida*, and *P. crispus*. The standing crop in these beds was by far the highest noted in the lake.

Areas 4, located in the uppermost portion of the lake, had the lowest standing crop of all beds in the lake. The area can generally be characterized as having unstable

Table 3. Rooted aquatic macrophyte species, frequency of occurrence, biomass, and total biomass of all species, Area 2, Lake Onalaska, 1976.

| SPECIES | F | AVERAGE BIOMASS (gm/m$^2$) |
|---|---|---|
| *Potamogeton crispus* | .53 | 56.64 |
| *Ceratophyllum demersum* | .40 | 1.35 |
| *Cladophora spp.* | .40 | 24.61 |
| *Vallisneria americana* | .33 | 1.03 |
| *Heteranthera dubia* | .26 | 5.57 |
| *Elodea canadensis* | .20 | .35 |
| *Nymphaea tuberosa* | .20 | 6.12 |
| *Lemna trisulca* | .13 | 2.10 |
| *Potamogeton zosteriformis* | .06 | .26 |
| *Potamogeton pectinatus* | .06 | .11 |
| *Nelumbo pentapetala* | .06 | 2.00 |
| *Lemna minor* | .06 | .13 |
| *Myriophyllum spicatum* | .06 | .13 |
| TOTAL | | 100.40 |

Table 4. Rooted aquatic macrophyte species, frequency of occurrence, biomass, and total biomass of all species, Area 3, Lake Onalaska, 1976.

| SPECIES | F | AVERAGE BIOMASS ($gm/m^2$) |
|---|---|---|
| *Lemna minor* | .65 | 48.10 |
| *Ceratophyllum demersum* | .65 | 53.80 |
| *Elodea canadensis* | .50 | 94.64 |
| *Sagittaria latifolia* | .35 | 194.80 |
| *Heteranthera dubia* | .30 | 22.32 |
| *Nelumbo pentapetala* | .30 | 38.40 |
| *Najas flexilis* | .15 | 40.45 |
| *Sagittaria rigida* | .15 | 58.72 |
| *Potamogeton crispus* | .15 | 13.48 |
| *Vallisneria americana* | .10 | 1.32 |
| *Potamogeton richardsonii* | .05 | 15.20 |
| *Nymphaea tuberosa* | .05 | 1.18 |
| *Myriophyllum spicatum* | .05 | .22 |
| *Potamogeton nodosus* | .05 | 7.48 |
| *Cladophora spp.* | .05 | 1.14 |
| TOTAL | | 591.25 |

sediments but sufficient shallow water to support macrophytes. The average standing crop was 70.6 gm/m$^2$ (Table 5). The bulk of the standing crop was composed of S. latifolia and P. foliosis. The most frequently collected species, however, was Vallisneria americana (Table 5).

Area 5, located along the upper reach of Brice Prairie (Figure 2), had an average biomass of 85.4 gm/m$^2$ (Table 6). V. americana was collected in 85% of all samples taken in this area, and it comprised approximately one-fourth of the total biomass. Other significant species in this area were Ceratophyllum demersum, P. foliosis, and P. crispus.

Area 6, located along the middle portion of Brice Prairie, had a macrophyte standing crop of almost 280 gm/m$^2$, the second highest in the lake, exceeded only by Area 3. Sixteen species were collected in this area. V. americana was collected in approximately one-third of all samples (F = .36), followed by P. crispus, Cladophora spp., and Lemna minor (Table 7). Sagittaria rigida comprised the largest single contribution to the biomass (88.4 gm/m$^2$) (Table 7).

In summary, the stands of rooted aquatic macrophytes in Lake Onalaska were somewhat diverse, and the biomasses in the recognizable stands varied greatly. The highest standing crops were encountered in areas where they have been established for the longest periods of time. The addition of autochthonous material in these areas from the plants themselves obviously has contributed to these higher standing crops.

The absence of macrophytes in the central portion of the

Table 5. Rooted aquatic macrophyte species, frequency of occurrence, biomass, and total biomass of all species, Area 4, Lake Onalaska, 1976.

| SPECIES | F | AVERAGE BIOMASS (gm/m$^2$) |
|---|---|---|
| *Vallisneria americana* | .76 | 8.75 |
| *Ceratophyllum demersum* | .24 | 1.15 |
| *Potamogeton foliosis* | .24 | 20.21 |
| *Heteranthera dubia* | .21 | .27 |
| *Potamogeton crispus* | .17 | 2.04 |
| *Sagittaria latifolia* | .14 | 30.81 |
| *Potamogeton richardsonii* | .07 | .64 |
| *Potamogeton nodosus* | .03 | 2.34 |
| *Nelumbo pentapetala* | .03 | .24 |
| *Nymphaea tuberosa* | .03 | 4.14 |
| TOTAL | | 70.60 |

Table 6. Rooted aquatic macrophyte species, frequency of occurrence, biomass, and total biomass of all species, Area 5, Lake Onalaska, 1976.

| SPECIES | F | AVERAGE BIOMASS ($gm/m^2$) |
|---|---|---|
| *Vallisneria americana* | .85 | 24.20 |
| *Ceratophyllum demersum* | .54 | 12.02 |
| *Potamogeton foliosus* | .33 | 18.51 |
| *Potamogeton crispus* | .24 | 12.80 |
| *Elodea canadensis* | .22 | 4.83 |
| *Cladophora spp.* | .06 | .74 |
| *Sparganium eurycarpum* | .04 | 1.61 |
| *Nymphaea tuberosa* | .04 | .40 |
| *Myriophyllum spicatum* | .02 | .02 |
| *Potamogeton pectinatus* | .02 | 1.90 |
| *Potamogeton richardsonii* | .02 | 8.43 |
| TOTAL | | 85.46 |

lake was probably related to wind action. Wind-generated waves created unstable sediment situations and removed the fine particles. In spite of the fact that the depth in these areas (Areas 6 and 7, Figure 1) were such that mature macrophyte beds could exist, the resistance to growth by wind action has to date prevailed. With the continued loss of depth, however, it would be expected that a rapid encroachment of macrophytes into these areas is inevitable.

Table 7. Rooted aquatic macrophyte species, frequency of occurrence, biomass, and total biomass of all species, Area 6, Lake Onalaska, 1976.

| SPECIES | F | AVERAGE BIOMASS (gm/m$^2$) |
|---|---|---|
| *Vallisneria americana* | .36 | 22.50 |
| *Potamogeton crispus* | .32 | 10.94 |
| *Cladophora spp.* | .24 | 3.53 |
| *Lemna minor* | .22 | 5.12 |
| *Sagittaria rigida* | .16 | 88.40 |
| *Nelumbo pentapetala* | .16 | 30.30 |
| *Ceratophyllum demersum* | .14 | 3.40 |
| *Elodea canadensis* | .12 | 3.60 |
| *Potamogeton nodosus* | .12 | 20.50 |
| *Sagittaria latifolia* | .12 | 73.34 |
| *Potamogeton pectinatus* | .10 | 5.78 |
| *Najas flexilis* | .08 | 4.08 |
| *Potamogeton foliosis* | .06 | 3.37 |
| *Heteranthera dubia* | .06 | 2.42 |
| *Nymphaea tuberosa* | .04 | 1.36 |
| *Potamogeton richardsonii* | .02 | .58 |
| TOTAL | | 279.22 |

## Nutrients

Because the sampling period for this study did not extend over at least one entire year, nutrient budgets could not be calculated. However, nitrogen and phosphorus relationships between water, sediment, and macrophytes were determined in two independent studies (Smart and Strodthoff, unpublished data). The release and uptake of these two elements were examined during 1975 and 1976 to determine the contribution that macrophytes make in mobilizing nutrients from the sediments, and consequently make them available either for transport out of the system to the river or to other organisms (such as phytoplankton). Analyses of data for *Sagittaria latifolia*, *Nelumbo pentapetala*, *Nymphaea tuberosa*, and *Ceratophyllum demersum* are summarized in Table 8. To arrive at these summaries, the average sediment, plant, and water values for the total nitrogen and total phosphorus were calculated for four three-month periods. The total areas of established vegetation beds in Lake Onalaska were calculated by planimetry, and the nutrient data were expanded to these areas. Whereas the calculations are approximations and disregard vegetation in the lake that existed at densities less than 80 plants/$m^2$, they can probably be considered as indicative of the general state of eutrophy for the lake. By calculating the total uptake of nitrogen and phosphorus by these plants during the growing season (spring and Summer) and subtracting these values from the amount that was released during periods of decomposition, (autumn and Winter) it becomes apparent that there is a net increase of both elements in the lake system of approximately 5,000 kg and 1,300 kg. of nitrogen and phosphorus, respectively. These approximations are no doubt low since some rooted aquatic macrophytes and all phytoplankton were disregarded. These excesses are available for transport out of the system. Because of the extremely long turnover time for the more isolated portions of the lake, however, the bulk of the excess nutrients in these areas are retained in the sediments. This can be supported by the high standing crops of macrophytes observed in Areas 3 and 6. The ratio of nitrogen to phosphorus on a molar basis is approximately 13:1, which is indicative of a highly eutrophic state.

Table 8. Total resident Nitrogen and Phosphorus in rooted aquatic macrophytes (June-July) and average uptake and release rates for Spring, Summer, Winter, and Autumn, 1975-1976, Lake Onalaska.

| AREA | TOTAL RESIDENT (Kg) | | RELEASE AND UPTAKE (Kg) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | SPRING | | SUMMER | | AUTUMN | | WINTER | |
| | N | P | N | P | N | P | N | P | N | P |
| 1 | 105 | 220 | -86 | -14.7 | -8.2 | -2.8 | 316 | 62 | 60 | 6.6 |
| 2 | 3682 | 773 | -451 | -76.8 | -432 | -14.8 | 1644 | 323 | 315 | 34.6 |
| 3 | 2847 | 597 | -496 | -84.4 | -476 | -16.3 | 1809 | 355 | 347 | 38.1 |
| 4 | 5187 | 1088 | -667 | -113.7 | -641 | -21.9 | 2436 | 478 | 467 | 51.3 |
| 5 | 5766 | 1210 | -254 | -43 | -243 | -8.3 | 926 | 182 | 177 | 19.5 |
| 6 | 14135 | 2967 | -293 | -5.0 | -282 | -9.6 | 1072 | 210 | 206 | 22.6 |
| TOTAL | 32622 | 6855 | -2247 | -337.6 | -2156 | -73.7 | 8203 | 1610 | 1572 | 172.7 |

NET TOTAL NITROGEN RELEASE +5372 Kg

NET TOTAL PHOSPHORUS RELEASE +1371.4 Kg

# RECOMMENDATIONS

The recommendations offered in this report reflect only possible methods that could have ecological significance within the confines of Lake Onalaska. There is no consideration of the economic feasability of any of the methods discussed. The recommendations are related to the following observable phenomena that have occurred in the lake and presumably will continue to occur in the foreseeable future.

1. Loss of volume due to the transport of bed and suspended load from the Mississippi River;
2. The subsequent establishment of rooted vegetation in peripheral areas in the lake;
3. The rapid accumulation of nitrogen and phosphorus in the lake;
4. The loss of species diversity associated with the above-named phenomena;
5. The ultimate transformation of the lake into a marsh-like habitat.

The possible remedial activities that could be undertaken to alleviate the problems associated with eutrophication can be categorized as follows:

1. Watershed improvement;
2. Hydrologic alterations to either divert flow into or out of the lake;
3. Dredging, to increase habitat diversity;
4. Chemical treatment and harvesting of rooted aquatic macrophytes.

### Watershed treatment

Because of the vastness of the watershed of the Mississippi River, there would appear to be virtually no methods available to alleviate the inflow of materials to the lake.

### Closure of existing water supplies from the Mississippi River

The hydrographic data indicate that one channel (No. 2, Figure 1) supplies approximately 90% of the total inflowing water to the lake. The closure of these three channels would alleviate the sediment inflow to the lake during periods of high flow as well as normal flow periods. However, the creation of new openings would be necessary to decrease the capacity-inflow ration and to flush the system. This could possibly be accomplished by opening channels into the lake from upstream areas and by allowing the water to de-silt prior to its entry into the northern-most reaches of the lake. Obviously, the transitional areas between the Mississippi River and the lake itself would undergo rapid change due to the accumulation of sand and silt. Consequently, this would still be a temporary measure, since the transitional areas would become saturated with sediment materials in a few years.

### Installation of a control structure in the main feeder channels

By installing control gates across the primary feeder channels into the lake and keeping them closed during periods of high flow, a major portion of the total transported sediment load could be diverted away from the lake. It is estimated that approximately 80% of the total load carried by the Mississippi River is carried during periods of flood. (USACE personal communication, 1976). The control structure would remain open during periods of normal flow to accommodate normal flushing action.

### Improvement of septic facilities for Brice Prairie inhabitants

Whereas nutrient leaching from lakeshore septic systems is inevitable, the input from Brice Prairie is probably insignificant when compared to the total nutrient budget. Thus, replacement of more efficient systems in that area would probably have little or no effect on the total nutrient structure of the lake.

### Dredging

Hydraulic dredging in the areas adjacent to the barrier islands that separate the lake from the Mississippi would enhance the system since the creation of deep holes would increase the habitat diversity. However, the disposal of the dredged material in an ecologically sound manner would pose problems. It would appear that the creation of islands in the open portion of the lake would be disadvantageous in that their presence would stimulate the growth of rooted vegetation on the wind-protected side of the structures. Because of the time required for stabilization of the dredged material by the growth of terrestrial vegetation and the ten percent slope that is created by the outfall of the dredged material, it is highly probable that the dredged material would be distributed by wind and water erosion before it could become stabilized. In addition to this, the dredge, whether hydraulic or otherwise, would have to dredge an access channel to the dredging site.

### Chemical treatment and mechanical harvesting of macrophytes

These measures, while providing temporary local relief, do not address the primary cause of the problems associated with eutrophication. In Lake Onalaska, the rate of increase in growth of macrophytes exceeds the rate at which macrophytes have been treated with chemicals in past years. Obviously, the chemical treatment of these organisms, unless it is a pre-emergence treatment, does not alleviate the accumulation of organic material in the lake, but alters only the timing of decomposition. The killed-plant material simply dies earlier and still contributes to the total resident nutrient supply. These methods do not offer any long-term solution to the problem.

It is apparent that the management of Lake Onalaska will be difficult if not impossible. Water levels cannot be controlled to such a degree that macrophyte beds can be exposed and subsequently removed. The lake, with its inherent trapping efficiency, will continue to progress toward a higher eutrophic state unless the hydrologic conditions of the system are radically changed.

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