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1975

Mixing Effects on Shallow Water Bodies

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MIXING EFFECTS ON SHALLOW
WATER BODIES

-

BY

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B.S.O.E., Florida Atlantic University, 1970

RESEARCH REPORT

Submitted in partial fulfillment of the requirements
for the degree of
Master of Science in Environmental Systems Management
in the Graduate Studies Program of
Florida Technological University

Orlando, Florida
1975

ACKNOWLEDGEMENTS

ABSTRACT

MIXING EFFECTS ON SHALLOW WATER BODIES

By
Kim Robin Powell

This report is intended to examine the ecological changes due to mixing in shallow water bodies. Physical, chemical, and biological changes are reported in literature. A literature search revealed the range of mixing modes or processes. Assessment of ecological changes due to mixing by boating activities had been evaluated in a research project supported by the Environmental Protection Agency and conducted at Florida Technological University.

The examination of changes due to mechanical mixing on lake ecology simulated in fifty-five gallon drums indicated the sensitivity of such parameters as total Kjeldahl nitrogen, conductivity, pH, temperature and dissolved oxygen.

Problems of reproducibility and simulation are inherent in transporting sediments and water samples from a natural environment to an isolated barrel test. Even though care was taken to insure similar initial conditions for all water quality parameters in all of the drums, differences were recognized. The useful information from a pilot study of this nature comes from the relative comparison of each drum before and after mechanical stirring.

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1. OBJECTIVES

The objectives of this report are to examine available literature for natural and man-made mixing processes, parameters involved, and compare the findings with the results of a pilot study of mechanical mixing.

The range of effects of mixing and agitation will be cited in the literature search and the domain will be the examination of the sensitivity of parameters in a pilot study. The parameters under consideration are total Kjeldahl nitrogen, conductivity, pH, temperature, and dissolved oxygen.

The results of the pilot study will be presented in tabular form to facilitate the comparison between the measurements before and after mixing.

The results of this pilot study will be the basis for the conclusions on the sensitivity of the parameters investigated.

2. LITERATURE REVIEW

2.1. Natural Mixing

The processes and extent of natural mixing in Central Florida
lakes are of complex nature and not fully realized. Therefore, a
literature review of the basic processes will be presented.

2.1.1. Morphometric and Physical Features of Lakes

Fifty-five lakes and ponds in north-central Florida were sampled
over a one (1) year period by Shanon and Brezonik (13). They found that
this group of lakes were typically shallow and derived from solution
of limestone formations underlying the area. Stable thermal stratifi-
cation occurred in thirteen (13) lakes and temporary stratification was
found to be a common summer phenomenon in many of the shallow lakes.
Maximum depths of more than ten (10) meters were uncommon.

The shallowness of Florida's lakes suggests that thermal stra-
tification should be unimportant but Shanon and Brezonik found that
thermal stratification could occur in ponds as shallow as 3.5 meters.
Of interest here is that most Florida lakes do not exhibit the classi-
cal Birgean thermoclines with the stagnant hypolimnia but were found
to exhibit definite thermal stratification (13).

2.1.2. Wind Induced Mixing

Density and viscosity are among the most important hydraulic
properties of water, especially in laminar motion. They are used in
determining a value for the Reynolds number and enter into formulations
of the settling and conjunction of particles and resistance to flows.

Density variations in certain bodies of water result in seasonal strati-
fication and overturning of lakes and consequent mixing or wide varia-
tions in water quality.

Temperature is of profound importance to mixing in lakes. Tem-
perature variation can create a widely varying environment within a
lake and in a physical sense, it is partially responsible for the ver-
tical seasonal changes.

Wind puts this dynamic process in motion, winds sweeping over
water surfaces can create, through friction, a zone of circulation as
shown in Figure 1. Water that is driven to the windward shore of the
lake builds up a head which then generates return currents. The shore
and lake bottom topography determine the direction and magnitude of the
return currents. The return currents can travel at or below the water
surface. The returning currents begin downward in coves and begin
laterally where points of land jut out from shore (4).

In Figure 2 the velocity gradient for the current is usually
expressed dv/dz for the vertical axis of a cartesian system of coor-
dinates. The velocity differential must be replaced by the temporal
mean velocity gradient $\overline{dv/dz}$, which is given the symbol G as a shear
gradient. The shear gradient G has the dimensions $G = [L/TL] = T^{-1}$
and is usually expressed in sec^{-1}. Its magnitude is a function of the
power input relative to volume, C, of the fluid. The proportionality
factor, μ, has the same dimensions as the absolute viscosity and is
equal to it in laminar flow.

A specific relationship was developed by Camp and Stein for
shear along parallel planes of an elemental volume of water (4).
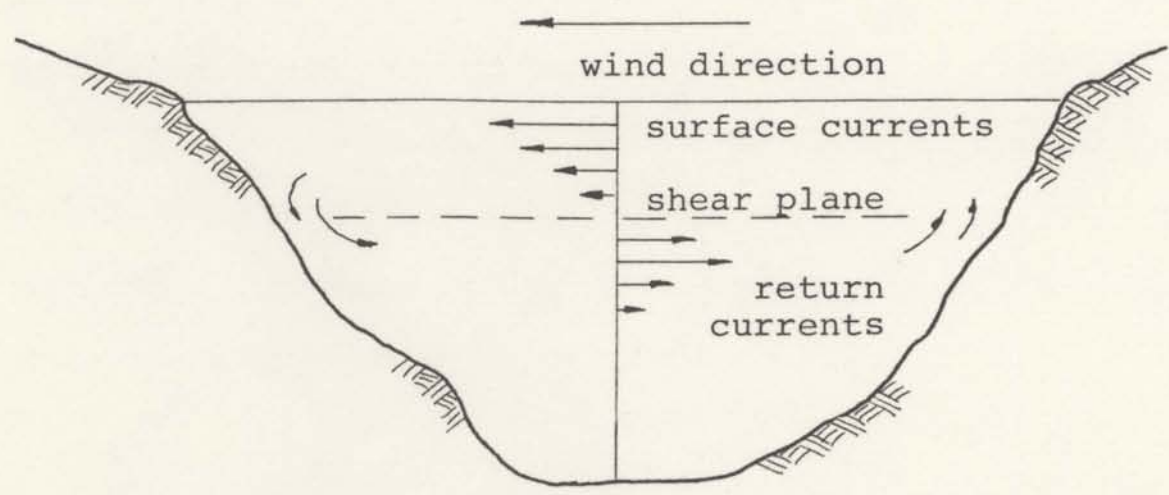
Fig. 1.   Idealized cross-section of a lake. This
figure displays the relative strengths
of the currents.   (4)
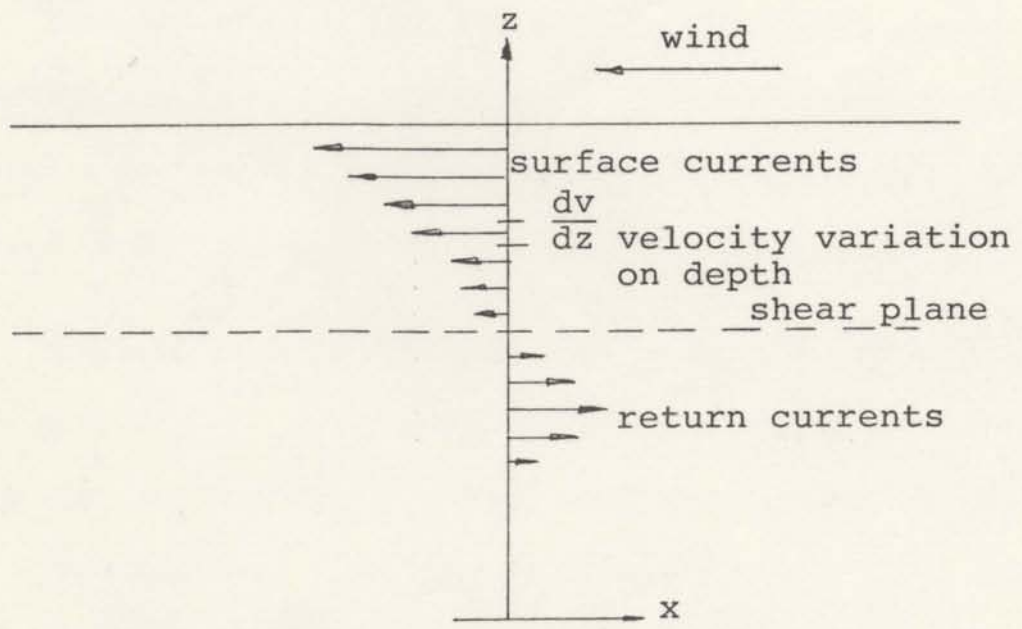
Fig. 2.   Elemental velocity differential.   This
figure displays the velocity variation on
a cartesian co-ordinate system.   The shear
gradient G is the temporal mean velocity
gradient $\overline{dv} / \overline{dz}$.

$$G = (P/\mu C)^{\frac{1}{2}}$$

The power input P is expressed in ft-lbs-sec^{-1}. The proportionality factor, , is expressed in lbs-sec-sq ft^{-1}, and C is the volume of the fluid measured in cubic feet.

If the power input is replaced by $[Q\rho gh_f]$ where Q is the flow rate in cubic feet per second, ρ is mass density in lb_m/ft^3, g is the gravitational constant, and h_f is the head loss in feet over the distance that the elemental volume of water travels then,

$$G = [(Q\rho gh_f)/\mu C]^{\frac{1}{2}}$$
$$G^2 = (Q\rho gh_f)/\mu C$$
$$G^2 = (\rho gh_f)/\mu t_d$$

The displacement time, t_d, in seconds, is for the quantity of water in the expression for flow Q. When Q and C are removed from the equation, t_d is left in the denominator.

A strip of water of unit width and length F is taken in the direction of the wind. The velocity of the wind-induced water current can be expressed as pW where W is the wind velocity and p is the proportionate surface velocity of the water (4).

$$G^2 = \rho g \, (pW)^2/4g \, t$$

The head loss, h_f, in feet, was replaced by the wind heated velocity head $(pW)^2/2g$. This head loss is used up in transporting the water through the length of the fetch and back to its point of origin in return flow. The associated time lapse is $2t_d$ where $t = F/(pW)$. Putting all the expressions together into one equation and simplifying we have:

$$G^2 = 9.3 \times 10^{-3} \, (pW)^3/\mu gF.$$

This expression relates the wind velocity, W, in miles per hour, and the fetch, F, in miles, to the mean temporal velocity gradient. Observed magnitudes of p lie between 1×10^{-2} and 5×10^{-2} and is known as

a unitless proportionate velocity.

2.1.3. Thermal Resistance to Mixing

Thermal resistance to mixing can be expressed in terms of temperature gradient. The greater the decrease in temperature with depth, the greater the thermal resistance to mixture and the more the return currents will be confined to the upper layer of water. Thermal resistance is meant here to describe the resistance of the colder, denser water to be displaced by the warmer, lighter surface water. A shearing plane can be found between the surface currents that follow the wind and the return currents (4).

Birge, noted for his work with thermoclines, has suggested that the work done by the wind against gravity in converting a column of water with uniform temperature gradient into a column of water with uniform density is:

$$W = (AL^2/12) \ (\gamma_2 - \gamma_1)$$

W is the work done (ft · lbs) by the wind, A and L are respectively the cross-sectional area (ft^2) and height (ft) of the column of water, and γ_2 and γ_1 are the specific weights (lbs · ft^{-3}) of the upper and lower layers of the water column (4).

As noted earlier, the standard Birgean thermocline was rare for Florida but thermal stratification was observed in most of the central Florida lakes (13).

Seasonal changes in temperatures are well known for their sequential thermal stratification and consequent spring overturning. Both the wind currents and temperature variations work together to account for much of the natural mixing processes.

2.1.4. Springs, Groundwater Discharge, Tides

Shanon and Brezonik concluded that Florida lakes generally have soft to moderately hard water. It was pointed out that this fact seemed contradictory to the solution origin of the lakes and the abundance of hardwater springs in Florida but made note of the fact that relatively few Florida lakes are spring fed. Most of them receive the bulk of their water either directly from precipitation or by surface and subsurface run-off. Several of the hardwater lakes are not naturally calcareous but culturally so through the influx of groundwater as treated sewage or septic tank drainage (13).

Available quantitative information is fragmentary and, in general, meager for groundwater discharge into lakes. In relation to mixing processes, groundwater discharge is generally thought of as a minor contribution because of the low velocities involved.

Tidal mixing becomes a prominant mixing process in coastal estuaries (17) but is of minor importance in considering mixing processes in central Florida lakes.

2.1.5. Mean Drift in Large Lakes

The natural horizontal displacement of water in lakes has been investigated. The surface drift in large northern lakes has been observed to be almost always in the counterclockwise direction. The observed mean speeds have been classified as slow and usually in the neighborhood of 0.1 cm sec^{-1}. Emery and Csanady (1973) have given an explanation in terms of the variations in wind stress at the lake surface induced by variations in water temperature (18).

Carl Wunsch has reviewed these explanations and presents a mathe-

matical explanation that shows that the Lagrange drift is at least a competitor with Emery and Csanady's hypothesis for stably stratified lakes. Wunsch's mathematical analysis was prompted by the observation of Kelvin waves with velocities as large as 30 cm sec^{-1}. Unlike Emery and Csanady's solution, reversals in the direction of the drift are predicted by Wunsch. He points out that this is a mathematical hypothesis and that observation may be able to distinguish between the two mechanisms (18).

2.1.6. Vertical Entrainment in Stratified Lakes

The vertical entrainment in the epilimnia of stratified lakes was examined by Jackson O. Blanton. The density gradient separating the hypolimnion from the overlying epilimnion imposes somewhat of a barrier to the exchanges of heat and dissolved materials between these two layers. Two modes of mixing were proposed and included the direct entrainment of the denser water into the epilimnion by turbulence and mixing at the edge of the body of water where the pycnocline is located near the bottom (1). Figure 3 attempts to show these two processes.

Large lakes in the temperate zone were used by Blanton to test a one-dimensional model of entrainment because "when local entrainments are integrated over the entire area, advective effects are eliminated and the problem is reduced to a one-dimensional problem" (1). This model suggests that the growth of the volume of the epilimnion of a stratified lake is correlated with the mean stability over the period of growth.

In summary, the mean depth was cited as the single most important morphological parameter influencing the entrainment rates. Also the wind energy input was positively correlated with the basin dimen-

Mixing zone transferring heat and materials to epilimnion.

Entrainment of heat and materials into epilimnion between times 1 & 2.

Stationary profile of nutrients

density $\longrightarrow$

low $\longrightarrow$ high

epilimnion

h_1

depth

hypolimnion

——— time 1

— + + — time 2
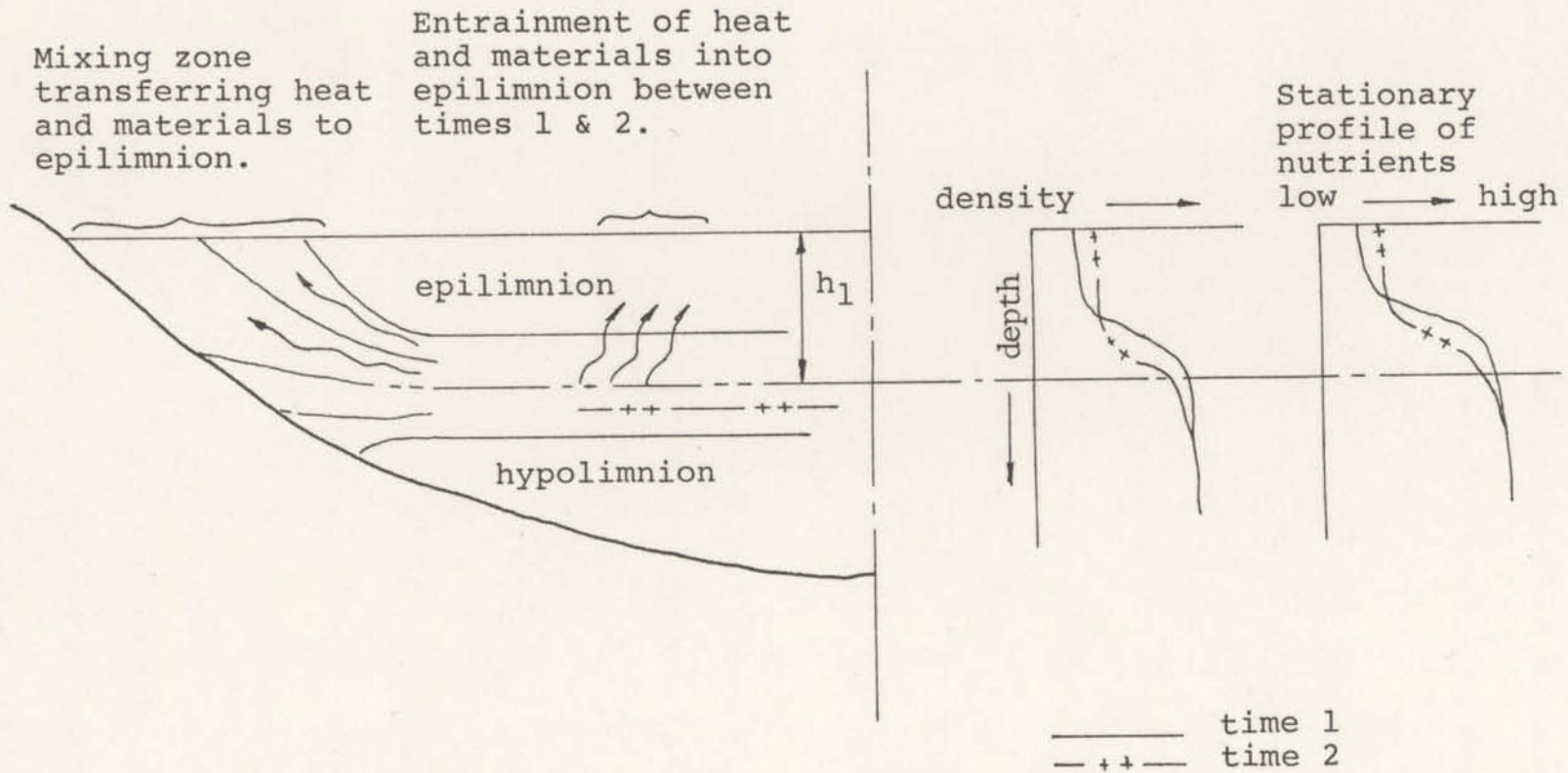
Fig. 3. Two natural modes of mixing. This schematic diagram showing two modes whereby water in the hypolimnion may be transferred to the epilimnion. (1)

sions. The value of the study lies in the fact that entrainment may regulate primary production in some stratified lakes.

2.1.7. Diffusive and Convective Transport Processes

The changes in the concentrations of certain parameters in a natural body of water can result from two distinct processes. Responsible for these changes can be advective and/or dispersive mass transport of materials across system boundaries or the changes may result from reactions or processes which occur within the system boundaries. Of interest here is the review of the transport processes.

For transport processes, the magnitude of the dispersive transport is a function of the distribution of components, or concentration gradients within the control volume. Advective transport of material is accomplished by bulk flow (16).

Analysis of process dynamics involves an analysis of two aspects of the changes that result. First it is necessary to know the extent of change and second, how fast the change occurs.

The time requirement to distribute a substance homogeneously throughout a system can vary greatly. The mechanism of mass transfer or transport in a quiescent system is the random molecular motion of the molecules. In a dynamic system that is being mixed either naturally or artificially the transient characteristics of the flow quickly diminish the concentration gradients. These two distinct modes of transport are termed molecular or diffusive mass transport and convective mass transport.

The continuity equation is basic in applying mathematics to theoretical hydraulics and generally takes the form of a partial differential equation involving both the concentration and the flux of a

certain component. The component could be a parameter such as nitrogen.

Diffusive Mass Transport. For diffusive mass transport, the continuity equation requires that the expression for mass transfer relate the flux of a diffusing molecule to it concentration gradient of a system. An empirical expression was proposed by Fick (1855).

$$F_{iz}^{o} = -D_{li} \frac{dCi}{dz}$$

This is generally referred to as Fick's first law. F_{iz}^{o} is the flux of component i in the z direction in a isothermal and isobaric system. D_{li} is the diffusivity or diffusion coefficient for the component i. This relation holds for dilute solutions where values of D_{li} range from aoubt $.5 \times 10^{-5}$ cm^2/sec to about 5×10^{-5} cm^2/sec. Also, this description of a mass transport process is for concentration gradients in quiesent or laminar flow systems (16).

Convective Mass Transport. Bulk flow is likely to be turbulent rather than laminar and the rates of mass transport in turbulent systems are many times larger than in laminar flow systems. To characterize turbulent flow regimes, Prandtl proposed the mixing-length hypothesis. The vector form of the equation is:

$$\vec{j}_i = (D_{li} + E_D) \nabla C_i + \vec{v}C$$

The mass flux, $\vec{j}_i$ is a vector, the magnitude of which represents the mass of i per unit area per unit time crossing and infinitesimal surface normal to the direction of flow. The eddy dispersion coefficient is E_D, and the average mass velocity of the mixture is $\vec{v}$. Of course, ∇ is the del operator (16).

This section on diffusive and convective mass transport should serve as an introductory survey of the mathematical approach to

theoretical hydraulics. Theoretical solutions to transient hydraulics problems are rarely simple. Computer and graphical methods are of great help in obtaining these solutions.

2.2. Man Made Mixing

The central Florida area has had a substantial population growth over the past twenty years and water recreation has increased proportionately. Outboard motorboats have increased both in horsepower and number of boats to be allowed per unit area of surface water. However, it is desirable to protect the environment from undesirable changes.

Of interest to fishermen, recreationalist, environmentalist, and certainly to every outboard manufacturer, are the results of lengthy studies undertaken to determine to what extent, if at all, modern outboard motors pollute the environment and what effects such pollution might have on the aquatic environment. The mixing effects due to the combined action of the propeller and hull are of prime interest in this paper.

2.2.1. Thermal Destratification to Arrest Oxygen Deficiency

Oxygen deficiency in Florida lakes has been considered for years. Aeration aids in the elimination or prevention of certain pollution problems have been cited as a possible solution to the elimination of fish mortality caused by oxygen deficiency. Results have not been uniformly successful.

Several thermally stratified lakes in the central Florida area are theoretically capable of producing power to reduce oxygen deficiency according to one feasibility study (6). It was recommended by this

study that a thermal differential power generating system, augmented by a flat-plate solar energy absorber, he built and used in appropriate lakes. Also, it was recommended that an air lift device be included in the system to increase the rate of oxygen uptake and reduce thermal stratification.

2.2.2. Ecological Management Considerations

Optimum management of certain bodies of water have often been hindered by thermal stratification. Fish die-offs, limited recreational activity, and even consumptive use problems have been identified, directly or indirectly, with thermal stratification. Most destratification studies have shown improvements in water quality pertaining to chemical problems (8). Also it was found that by cooling the surface water by destratification a potential benefit of reduced evaporation incurred (9,15).

The influence of thermal destratification on biological components was examined by R. T. Lackey (8). It was reported that fisheries scientists have often attempted aeration by thermal destratification with some attempts being successful in preventing winterkill. Other attempts at commencing winter aeration when dissolved oxygen was low caused an immediate decrease of dissolved oxygen and an increase in iron (8,9).

Bottom fauna response to artificial destratification is perhaps the least understood biological aspect. Certain research work indicates that some benthic species including midget larvae and pupae and nematode worms quickly invaded the profundal zone following destratification. This fauna research work was performed on the El

Capitan Reservoir, California, and cited by R. T. Lackey. The point indicated here is that artificial destratification may or may not be desirable. Decreases in thermal destratification may have a dramatic effect on the breeding habits of certain benthic species (8).

Before artificial mixing is employed either purposely or un-knowingly, certain biological studies should be made to assess the impact on the more sensitive species of the biological community. Chemical aspects of water quality may be improved at the cost of biological balance.

2.2.3. Mixing by Boating Activity

A recent research endeavor was directed towards an assessment of effects on water quality in shallow water bodies due to mixing by boating activity (20). The scope of the research included the definition of the problem, isolation of effects and conditions and determination of areas for further research.

Recent studies have been directed towards the environmental impact of the exhaust emissions (5) but of interest here is the environmental impact of agitation and mixing due to boating activity. Such a study was undertaken at Florida Technological University and was sponsored by the Environmental Protection Agency (1974) (20).

The four lakes selected for the study were all in Orange County with three of the lakes supporting heavy boating activity and the fourth lake supporting, by regulation, virtually no boating activity. Boats equipped with different horsepower were run for limited periods of time in sampling areas which vary in depth between 1.2 and 10.7 meters. Changes in certain water quality parameters due to mixing by boating activity

were documented.

Results indicated that mixing of water column could be revealed by the measurement of dissolved oxygen and/or turbidity. In the shallow eutrophic lakes, where stratification and oxygen depletion in the hypolimnion exist, artificial mixing could result in considerable reduction of dissolved oxygen in the upper layers. In shallow lakes which were not stratified, with oxygen levels close to saturation, turbidity was a very useful indicator of mixing.

Test conditions indicated that mixing depth varied directly with the horsepower of the motor. A 50 horsepower motor effectively mixed up to a depth of 15 feet.

The sediments in small lakes are formed mainly from material brought from the shoreline. Resuspension of these solids from the bottom was observed and documented with changes in turbidity being dependent upon the depth. An hour after boating activity ceased, a decrease in turbidity measurements was observed.

Temperature, pH, conductivity and TKN were deemed poor indicators of mixing in the lakes tested.

Recommendations by this research report included: (1) The examination of the impact of mixing the lower levels of water, that were rich in phosphorus, throughout the water column; (2) Examination of the factors that increase oxygen by boating activity; (3) The effect of the boating activity on the thermocline; and (4) Identification of the mixing processes.

3. PILOT STUDY

3.1. Preliminary Consideration for the Pilot Study

A pilot study in fifty-five gallon drums was undertaken in order to compare between results obtained from full scale lakes and simulated ecosystems.

Three steel barrels were chosen and painted with white paint on the inside. The barrels were then positioned in the shade and embedded in the ground so as to bring the full water level approximately to ground level. Ten to fifteen centimeters of lake bottom sediments were added and then the barrels were filled with water from Lake Claire, covered with a sheet of plexiglass and allowed to equilibrate for approximately two weeks.

The three barrels were labeled and contained water approximately one meter deep. Barrel #1 received no stirring for the duration of the experiment. Barrel #2 received moderate stirring, and barrel #2 received the most stirring.

The electric motor stirring devices were positioned above and in the center of barrels #2 and #3. The axis of rotation of the stirring shafts was vertical and extended approximately twenty centimeters into water approximately one meter deep.

The impellers were simple in construction and made from heavy gauge stainless steel. The impellers were three bladed with each blade being flat and with an attack angle of approximately forty-five degrees The diameter of the impellers were approximately three centimeters.

Each stirring device was an assembly of a constant speed electric motor, a disc assembly, and a variable length shaft.

The 100 volt electric motor was 60 cycle and ran at a constant speed. A disc assembly was factory built and fitted to the electric motor. This disc assembly allowed the adjustment of impeller speed without changing the electric motor speed. Impeller speed for barrel #2 was approximately 200 revolutions per minute and 600 revolutions perminute was the approximate impeller speed for barrel #3.

Barrel #3 received as much stirring as the stirring devices could generate without allowing any cavitation. The combination of the circular barrel and the positioning of the stirring device allowed vortices to be generated easily and form a "sink drain effect." This in turn would allow air and water vapor to appear at the impeller. Power input was, therfore, kept below the level that allowed cavitation to occur.

3.2. Methods and Instruments used in Analysis

3.2.1. Temperature and D.O. Measurement

Temperature and dissolved oxygen concentrations were measured at specific times in the field by the use of the portable YSI 54 Oxygen Meter. The membrane electrode was calibrated every day before use in the laboratory and water samples were collected and fixed in the field to check the calibration of the D.O. Meter. The azide modification of the iodometric method as described in the standard methods for the examination of water and wastewater was used to check the calibration (14). It was found essential to avoid air bubbles on the membrane

surface because this significantly increased the D.O. readings.

3.2.2. Conductivity, pH, and Turbidity Measurements

The conductivity measurements were performed in the field by the use of the portable Lab-Line Lectro Mho-Meter Model MC-1, Mark IV.

The hydrogen ion concentration was measured in the field by the use of a Corning Model 610 Portable pH Meter. Calibration was easily performed in the field by the use of two buffer solutions of known pH values.

Special samples were taken in glass and immediately returned to the laboratory for turbidity measurements on the Hach 2100 turbidi-meter.

3.2.3. Total Kjeldahl Nitrogen Determination

Nitrogen determination was, by far, the most sensitive and most difficult analysis to be performed. Samples were taken in glass and preserved with mercuric chloride solution for analysis in the laboratory.

Nitrogen is commonly found in the (-III) state during water analysis and is referred to as Total Kjeldahl Nitrogen (TKN). Total Kjeldahl Nitrogen is differentiated into organic and amonia nitrogen but for the purpose of this study only the TKN concentrations were needed for comparison on a relative basis (12).

To determine TKN, a Kjeldahl digestion followed by distillation is conducted on the entire sample. In this method, the procedure was completed by nesslerization of the distillates, analysis on a Beckman DB-GT Spectrophotometer, using a standard curve and a simple calculation to adjust for sample size. Appendix A contains the procedure used in

this analysis.

The analysis for TKN has many places for error to enter. Errors may result from the inability of the digestion procedure to convert all organically bound nitrogen to ammonia and/or incomplete hydrolysis of organic nitrogen-containing compounds to ammonia during the distillation step. A certain amount of proficiency and reliability was gained in the previous summer term by completing this test on more than one hundred fifty samples.

3.3. Discussion of Procedure and Results

After the initial acclimation period of two weeks, the stirring devices were turned on in the morning and turned off in the afternoon of each day for three consecutive days. Tests on all parameters were taken before the start of the mixing period and at specified intervals throughout each day.

Drum #1 was used as a control with no artificial mixing while Drum #2 and #3 received moderate and vigorous mechanical mixing respectively.

An average increase in turbidity and kjeldahl nitrogen concentration from mechanical mixing was noticed for drums #2 and #3 as shown in Table 3.1. Table 3.1 represents the average change in water quality parameters due to mixing while detailed data is presented in the appendices.

From Table 3.1, it can be noticed that the pH varied between 7.0 and 7.4, the conductivity varied between 87 and 125, turbidity varied between 1.33 and 5.25, and TKN varied between 0.25 and 0.51 in

TABLE 3.1

AVERAGE CHANGES IN WATER QUALITY
PARAMETERS DUE TO MIXING

Drums	Parameters					
	Turbidity (JTU's)	TKN (mg/1)	pH	Conductivity (μ mho/cm)	Temperature (°C)	D.O. (mg/1)
Drum #1 No Mixing	1.50	0.29	7.4	125	13	8.7
	1.33	0.33	7.3	124	13	9.3
Drum #2 Before Mix	3.42	0.25	7.2	87	12	8.8
After Mix	5.25	0.48	7.3	87	12	8.3
Drum #3 Before Mix	1.33	0.31	7.0	100	11	7.5
After Mix	4.75	0.51	7.2	100	11	8.0

The values in Table 3.1 represent the average values for the three consecutive days of the study. The dissolved oxygen values are the average of the surface values of each drum.

all three drums. Drum #2 and #3 showed higher values of turbidity
and TKN after mixing as compared to the same parameters in Drum #1
with no mechanical mixing. The pH and conductivity did not show ob-
vious change due to mechanical mixing.

Temperature was very constant throughout this study. Tempera-
ture varied less than $0.5^{\circ}C$ throughout the one meter depth and from
drum to drum. On December 10, 11, and 12, the temperatures were
$13^{\circ}C$, $12^{\circ}C$, and $11^{\circ}C$ respectively.

Dissolved oxygen varied between 7.5 mg/l and 9.3 mg/l. These
average values for the surface concentrations did not display an ob-
vious trend.

From Appendix C (Dissolved Oxygen Daily Average) it can be ob-
served that on December 10 and 11 the dissolved oxygen values were
lower at mid-depth than at the bottom. On December 12, the values
appeared normal with the highest value at the surface and the lowest
value at the bottom. When the mid-depth dissolved oxygen value was
lower than the bottom value, the difference was never more than 1.0
mg/l.

Problems of reproducibility and simulation are inherent in
transporting sediments and water samples from a natural environment
to an isolated barrel test. Even though care was taken to insure
similar initial conditions for all water quality parameters in all of
the drums. differences were recognized. The useful information from a
pilot study of this nature comes from the relative comparison of each
drum before and after mechanical stirring.

3.4. Conclusions and Recommendations

1. The parameters that displayed the greatest change in concentration are:

    a.   Turbidity - values in Appendix D display the marked relative differences between being mixed and unmixed. Values for turbidity typically doubled and tripled depending on the mixing conditions.

    b.   Nitrogen - values for TKN (Appendix B) typically doubled depending on the mixing status. Much more time was required to test for TKN than any other parameter. Also, it was deemed the most sensitive to error of any of the parameters investigated by this study.

    c.   Dissolved Oxygen - values for dissolved oxygen (Appendix C) typically ranged from approximately 7.0 to 9.5 mg/l.

2. The parameters that displayed the smallest changes are:

    a.   pH - values for pH ranged from 6.25 to 8.30 (Appendix E).

    b.   Conductivity - values in Appendix F typically displayed changes in the 1% range.

    c.   Temperature - this parameter was deemed the most stable of all parameters examined.

3. Temperature ranged from $13^{\circ}C$ on the 1st day to $11^{\circ}C$ on the third day and varied less than $.5^{\circ}C$ for any given day. This study took place during the winter and should not be taken as typical for all seasons.

4. The pH tended to stabilize on the third day of mixing around 7.3 to 7.5. The first pH readings were erratic and varied as much as 1 pH unit.

5. Dissolved oxygen was generally higher at the surface than at mid-depth and bottom but it can be seen in Appendix C that the dis-

solved oxygen values were slightly lower at mid-depth than at the bottom. This is not a typical occurence in general but was typical in this pilot study.

      6. The effects of mixing in the vicinity of the impeller on oxygen uptake warrent further investigation.

APPENDIX A

PROCEDURE USED IN TOTAL KJELDAHL
NITROGEN DETERMINATION (14)

1) Cleaning: Rinse with Chromic Acid and then with distilled H_2O.

2) Place measured sample (500 ml) into an 800 ml Kjeldahl flask. The sample size can be determined from this table.

Assumed Kjeldahl Nitrogen in Sample (mg/l)	Sample Size (ml)
0 - 5	500
5 - 10	250
10 - 20	100
20 - 50	50
50 - 100	25

Dilute the sample, if required, to 500 ml and add 100 ml sulfuric-acid-Mercuric sulfate-potassium sulfate solution and evaporate the mixture (under the hood) in the Kjeldahl apparatus until SO_3 fumes are given off and the solution turns colorless or pale yellow. Cool residue and add 300 ml water. (I assumed here that 300 ml should have evaporated and the addition of 300 ml H_2O would bring volume back to original 500 ml.)

3) Make digestate alkaline by adding sodium hydroxide-thiosulfate solution without mixing (20 ml of $36NH_2SO_4$ requires approximately 60 ml of 17.5 N $NaOH-Na_2S_2O_3$ to neutralize). (The addition was performed by the use of a 50 ml and 10 ml pipette. The mixing is performed after the

800 ml Kjeldahl flask is connected to the Kjeldahl distilling apparatus.)

4) Connect the Kjeldahl flask to the condenser. The tip of the condenser should be fitted with an extension that protrudes below the level of boric acid solution in the receiving flask.

5) Distill 300 ml into the receiving flask. The rate should be 6-10 ml/min. The receiving flask should contain 50 ml boric acid solution (2%) and the flask size should be 500 ml and glass stoppered. (Rubber stoppers were used.) (It is anticipated that ammonia measurement will be made by nesslerization.)

6) Dilute the distillate to 500 ml in the flask and nesslerize and aliquot to obtain an approximate value of the ammonia-nitrogen concentration. Concentrations above 1 mg/l should be titrated.

7) Colorimetric determination. Prepare a series of Nessler tubes as follows:

ml of Standard Solution 1.0 ml = .01 mg NH_3N	Concentration when Diluted to 50.0 ml mg NH_3N/liter
0.0	0.0
0.5	0.10
1.0	0.20
1.5	0.30
2.0	0.40
3.0	0.60

Dilute each tube to 50 ml with ammonia free H_2O, add 1.0 ml of nessler reagent and mix. After 20 minutes read the optical densities at a wavelength of 425 nanometers against blank. From values obtained plot optical density vs. concentration for the standard surve.

8) Determine the ammonia in the distillate by nesslerizing 50 ml or an alliquot diluted to 50 ml and reading the optical density of a wavelength of 425 nanometers as described above for the standards. Ammonia-Nitrogen is read from the curve.

9) Calculate the total Kjeldahl nitrogen in mg/l in the original sample from:

$$TKN = \frac{1000}{S} \quad \frac{50}{V} \times N$$

where: S = sample size (mg/l)

V = volume of distillate nesslerized (mg)

N = milligrams of NH_3N read from standard curve
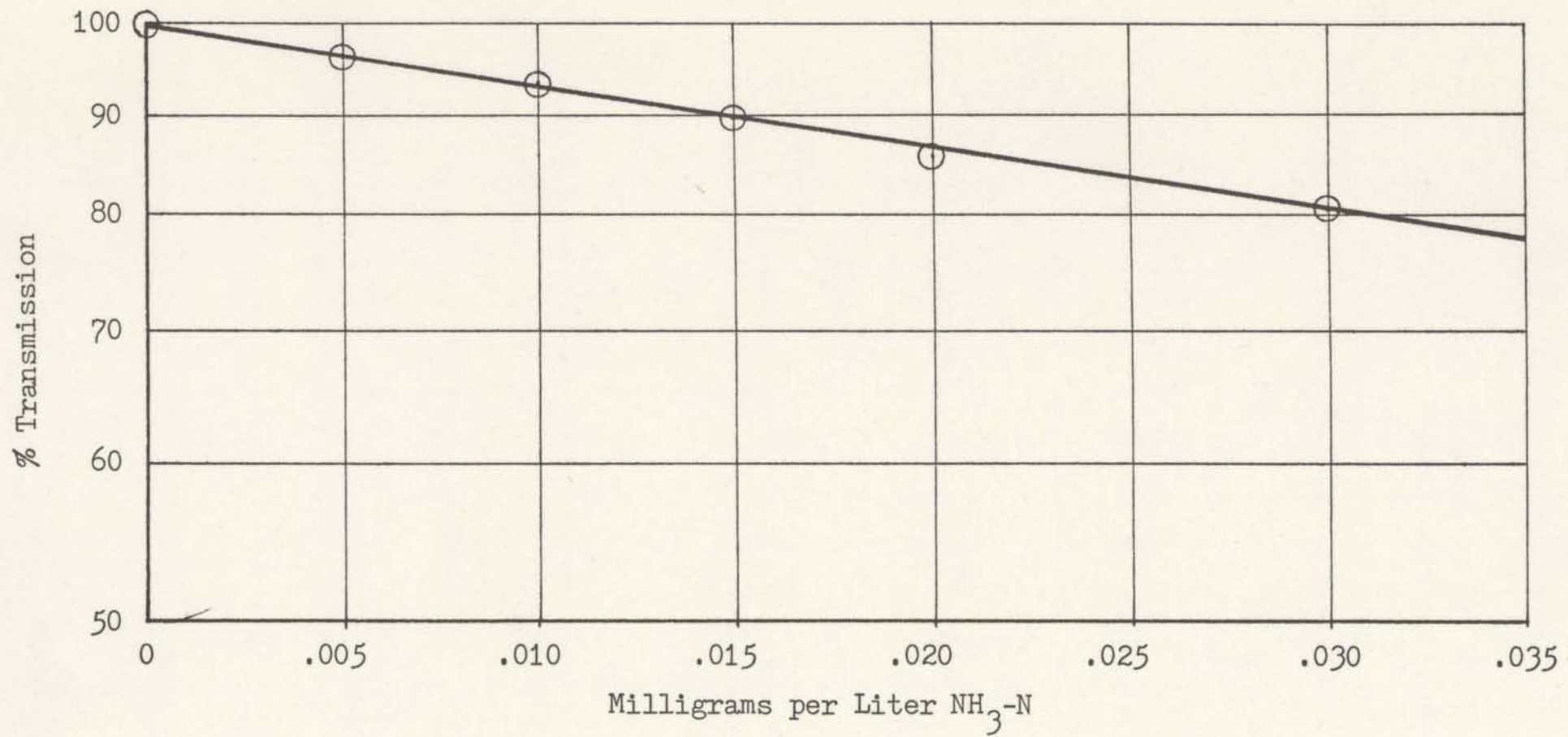
This standard curve was obtained through the use of a known standard NH_4Cl solution and the Beckman DB-GT Spectrophotometer. The Spectrophotometer was calibrated at a wave length of 425 nanometers.

APPENDIX B

TOTAL KJELDAHL NITROGEN TEST RESULTS
Units: (mg/l) as NH_3-N

Date	Mixing Status	Mixing Time (hrs)	Control Drum (No Mixing)	Drums Equipped With Mixer	
				Slow Mix	Fast Mix
			1	2	3
Dec. 10	Before		0.32	0.25	0.32
	After	3.0	0.32	0.51	0.54
Dec. 11	Before		0.30	0.22	0.32
	After	5.0	0.28	0.48	0.44
Dec. 12	Before		0.25	0.27	0.30
	After	5.5	0.38	0.45	0.54

Mechanical mixing in Drums #2 and #3 displayed a marked increase in Kjeldahl nitrogen concentration after being mixed. However, the average increases were approximately the same. The average increase for Kjeldahl nitrogen in Drum #2 was 0.23 mg/l and for Drum #2 was 0.19 mg/l.

APPENDIX C

DISSOLVED OXYGEN TEST RESULTS (DAILY AVERAGE)
Units: (mg/l)

| Date | Depth | Daily Average | | |
| | | Control Drum | Drums Equipped With Mixers | |
		No Mixing 1	Slow Mix 2	Fast Mix 3
Dec. 10	Surface	9.41	8.94	7.69
	Middle	8.71	7.76	6.68
	Bottom	8.98	8.21	7.21
Dec. 11	Surface	9.28	8.62	8.07
	Middle	8.65	7.60	7.35
	Bottom	8.76	7.77	7.44
Dec. 12	Surface	8.80	8.65	8.48
	Middle	8.10	7.65	7.78
	Bottom	7.87	7.55	7.23

An interesting phenomena is displayed in this table of daily averages for each drum. On December 11 and December 12 it can be seen that the lowest D.O. values are found at mid-depth (50 cm) in all three drums. On December 12, the D.O. values for all three drums were as might be expected with the lowest value at or near the bottom.

DISSOLVED OXYGEN TEST RESULTS
Units: (mg/l)

Date	Time	Surface			Mid-Depth			Bottom		
		No Mix #1	Slow #2	Fast #3	No Mix #1	Slow #2	Fast #3	No Mix #1	Slow #2	Fast #3
Dec. 10	10:00	9.2	9.1	7.0	8.4	8.0	6.0	9.6	8.9	7.2
	11:00	9.0	9.4	7.6	8.2	8.0	6.3	8.8	8.2	7.2
	12:00	9.0	9.2	7.6	8.2	7.8	6.7	9.3	8.4	7.0
	12:30	10.4	9.1	7.5	9.6	7.6	6.7	8.6	8.1	7.5
	1:00	8.8	8.4	8.1	8.4	7.6	7.1	8.9	7.9	*5.4
	1:30	10.4	8.9	7.9	9.8	7.7	7.0	8.9	8.0	7.5
	2:00	9.1	8.5	8.1	8.4	7.6	6.8	8.8	8.0	6.9
Dec. 11	9:15	8.8	9.2	7.6	8.3	7.8	6.9	8.9	8.3	7.6
	10:15	9.4	8.9	7.7	8.4	7.7	7.0	8.7	8.1	7.6
	11:00	9.0	9.2	9.3	8.3	7.8	8.7	8.6	8.1	*5.9
	12:15	10.6	8.5	8.3	10.0	7.8	7.2	9.6	7.5	7.6
	1:00	8.2	8.3	8.0	7.8	7.5	7.4	8.2	7.7	7.3
	2:00	9.7	7.6	7.5	9.1	7.0	6.9	8.6	6.9	7.1
Dec. 12	9:30	8.1	8.0	7.8	7.0	7.1	6.9	6.7	7.1	7.0
	10:15	8.0	8.5	9.0	7.7	7.3	8.5	7.9	7.6	*4.0
	11:00	10.6	9.2	8.6	9.2	8.2	7.6	8.5	7.8	7.5
	3:15	9.1	8.9	8.5	8.5	8.0	8.1	8.4	7.7	7.2

* These values for dissolved oxygen were assumed to be erroneous and therefore were excluded from the "Daily Averages" on the previous table.

APPENDIX D

TURBIDITY TEST RESULTS
Units: (JTUs)

Date	Mixing Status	Mixing Time (hrs)	Control Drum	Drums Equipped With Mixer	
			No Mixing 1	Slow Mix 2	Fast Mix ·3
Dec. 10	Before		1.75	3.50	1.50
	After	3.0	1.50	5.50	5.75
Dec. 11	Before		1.50	3.50	1.50
	After	5.0	1.25	5.00	4.50
Dec. 12	Before		1.25	3.25	1.00
	After	5.5	1.25	5.25	4.00

Marked increases in turbidity are displayed for Drums #2 and #3 during each mixing cycle while Drum #1 remained relatively constant. Drum #2 displayed an average increase in turbidity of approximately 1.8 JTUs while Drum #3 had an average increase of 3.4 JTUs.

APPENDIX E

pH TEST RESULTS
Units: (pH Units)

Date	Time	Control Drum	Drums Equipped With Mixer	
		No Mixing 1	Slow Mix 2	Fast Mix 3
Dec. 10	11:00 AM	7.4	8.3	6.25
	12:00 AM	7.5	7.5	7.5
	12:30 PM	6.9	7.1	6.9
	1:00 PM	6.9	6.9	6.9
	1:30 PM	7.0	7.1	7.0
	2:00 PM	6.9	7.0	6.9
Dec. 11	9:15 AM	*7.3	*7.0	*6.9
	10:15 AM	7.3	7.1	7.0
	11:00 AM	7.4	7.2	7.0
	12:15 PM	7.4	7.2	7.0
	1:00 PM	7.3	7.3	7.1
	2:00 PM	7.5	7.5	7.4
Dec. 12	9:30 AM	*7.5	*7.3	*7.1
	10:15 AM	7.4	7.3	7.1
	11:00 AM	7.5	7.4	7.3
	3:15 PM	7.5	7.4	7.2

In general, the pH values were not changed by the mechanical mixing process. *These pH tests were taken before the starting of the stirring devices for that particular day.

APPENDIX F

CONDUCTIVITY TEST RESULTS
Units: (μ mho/cm)

Date	Time	Control Drum	Drums Equipped With Mixers	
		No Mixing 1	Slow Mix 2	Fast Mix 3
Dec. 10	10:00 AM	*128	* 86	*101
	11:00 AM	128	87	101
	12:00 AM	125	87	100
	12:30 PM	127	85	98
	1:00 PM	128	87	101
	1:30 PM	129	87	102
	2:00 PM	128	85	101
Dec. 11	9:15 AM	*122	* 84	* 94
	10:15 AM	121	84	95
	11:00 AM	120	85	96
	12:15 PM	118	82	97
	1:00 PM	119	83	98
	2:00 PM	118	83	91
Dec. 12	9:30 AM	*126	* 90	*106
	10:15 AM	127	91	105
	11:00 AM	128	90	106
	3:15 PM	125	92	107

In general, the conductivity values were not changed by the mechanical mixing process. *These conductivity tests were taken before the starting of stirring devices for that particular day.

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