H. R. Schroeder

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

SOME EFFECTS OF SUSPENDED SEDIMENT ON GROWTH OF SUBMERSED PONDWEEDS

General Laboratory Report No. Gen-27

DIVISION OF ENGINEERING LABORATORIES

COMMISSIONER'S OFFICE
DENVER, COLORADO

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Commissioner's Office--Denver
Division of Engineering Laboratories
Chemical Engineering Laboratory Branch
Hydraulic Laboratory Branch
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General Report No. Gen-27*
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Subject: Some effects of suspended sediment on growth of submersed pondweeds

SUMMARY

A joint investigation by the Chemical Engineering Laboratory Branch and the Hydraulic Laboratory Branch was undertaken to study the shading effects of suspended sediments on certain hydrophytes. Species of submersed pondweeds, commonly found in irrigation canals, were planted in pots and grown in drums containing a range of suspended sediment concentrations. Ungerminated plant propagules and established cultures of pondweeds were used in the study.

Two different sediments were used, onea commercial sodium-base montmorillonite-type bentonite, and the other a natural occurring bentonite-type sediment obtained from Angostura Reservoir.

Light quantity and spectral quality, penetrating the sediment-laden water, were measured by use of a limnophotometer which has a specially constructed photoelectric cell system. Light measurements indicated the intensity and spectral quality of sunlight were considerably changed upon penetration into water containing suspended sediment. The sediment from Angostura Reservoir caused greater light reduction at lower concentrations than did the commercial bentonite.

When plants were exposed to reservoir sediment concentrations of 50 ppm, the percent reduction of dry weight of plant material was approximately 33 percent less than the dry weight of plant material in the control drum. Reservoir sediment concentrations greater than 1,250 ppm were not effective in producing additional significant growth reductions than that attained at the 1,250-ppm level. The commercial bentonite sediment caused growth reductions of a similar trend but required greater concentrations than field sediment to produce similar effects.

*Same as Laboratory Reports No. SI-21 and Hyd-450.

However, from this study, it appears that concentrations of suspended sediment greater than 1,250 ppm would have to be maintained in canal water to create plant growth inhibition that might be considered critical to the plant's survival. Maintaining a concentration of fine sediment of 1,250 ppm by weight in most canals appears generally infeasible.

A field study would be necessary to determine that shading from suspended sediments is the primary factor responsible for plant growth reduction. Many other environmental factors that affect the growth of pondweeds would have to be determined and observed in any type of field study. Obviously, optimum light availability is only one of the many interacting environmental factors that exhibit controlling influences over a plant's metabolic activity.

INTRODUCTION

In the past, field observations have frequently been made regarding a possible correlation between the amount of suspended sediment contained in canal water and the amount of aquatic plant growth in canals. Field observations have often indicated that as suspended sediment increases, the amount of aquatic weed growth decreases. Reports of observations reviewed have in no case given details of various factors contributing to suppression of aquatic plant growth. These statements have been of a general nature. To obtain more information under controlled conditions on this subject, a joint study by the Weed Control Investigations Unit of the Physical Investigations Laboratory Section,1/ Chemical Engineering Laboratory Branch, and the Sediment Investigations Unit of the Hydraulic Laboratory Branch was initiated to determine shading effects of suspended sediment on aquatic weeds. The scope of the program consisted of determining the growth response of various species of submersed pondweeds exposed to environment of various concentrations of two types of suspended sediments.

The study was made over a 2-year period. During the first year, the need for modification in procedures and techniques became evident. Therefore, data obtained in the initial test are not fully comparable to those obtained later.

MATERIALS AND METHODS

Construction of Special Equipment

Circulating systems designed to maintain fine sediment in suspension were installed in eight 55-gallon metal drums. The system consisted

1/ Weed control studies are conducted under a cooperative program between the Bureau of Reclamation, U. S. Department of the Interior; and the Agricultural Research Service, U. S. Department of Agriculture, Denver, Colorado.

mainly of a propeller driven by a 1/30-horsepower motor, a 26-1/2-inch-long by 2-1/2-inch-inside-diameter pipe, and a perforated false bottom, Figure 1. The propeller forced water, at a discharge of 0.147 cubic foot per second, through the 2-1/2-inch-diameter pipe at 4.31 feet per second (fps). Water spread beneath the false bottom and discharged through twenty-five 1/2-inch-diameter holes and a circumferential opening approximately 1/16 inch wide around the false bottom. Average velocity through these openings was 2.28 fps, and resulting upward velocity in the drum was approximately 0.055 fps, or 1.7 cm/sec. The 1/30-horsepower motors operated at 1,550 rpm and were designed to operate continuously while in the vertical position. Because tests were conducted outdoors, hoods were installed to keep the motors dry. To prevent possible phytotoxic contamination of the culture water, all submersed metallic parts were painted with an appropriate primer preparation and vinyl-based paint.

Limnophotometer Used for the Measurement of Radiant Energy

The limnophotometer was manufactured by a private instrument manufacturer in the United States and is similar to that described by Atkins et al(1)** for measurement of submarine daylight. This instrument consists basically of two selenium barrier-type photoelectric cells, one of which is sealed in a heavy brass case with a glass window. This unit is used for the measurement of subsurface illumination. Terminals of the submersible cell are connected to a waterproof electric cable to facilitate measurement of cell output current at the surface. The surface or reference cell is encased in a gimbal-mounted brass case. This unit is used to measure total (within sensitivity limits of the cell) radiant energy available at the water's surface.

Readings are obtained by measuring the electrical current emitted by the light-excited photocell on a microammeter contained in the control box. The meter is shunted to allow readings from direct connection to multiples of 10, 100, and 800. A selector switch enables the rapid switching from the surface to the submersed cell for comparative readings.

Flashed opal glass discs are used to cover each photocell. The opal glass serves to prevent variations caused by unequal light diffusion and to permit the measurement of oblique light rays. Both cells are equipped with detachable red and blue filters to allow separation and measurement of portions of the spectrum known to be efficient in photosynthesis. The red filter transmits wave lengths from 600 to 700 millimicrons, and the blue filter transmits wave lengths from 400 to 500 millimicrons.

The complete limnophotometer is shown in Figure 2. Figure 3 shows the spectral range of sensitivity of the photocells, transmission ranges of the filters, and spectral range of relative photosynthetic rates.

**Numbers in parentheses refer to references at end of report.

Calibration of the Limnophotometer

Calibrations of the individual photocells were made to obtain separate cell readings that would be comparable for calculation of percent light reduction. The two cells varied considerably in their output at a given energy level. The submersible cell output was less than the surface cell output. This was due to individual cell characteristics and a thicker cover glass on the submersible cell. These differences were compensated for by increasing the submersed cell readings in all reported light data. This was accomplished by calculating average differences of the two cells from numerous light measurements at varying energy levels to obtain a correction factor.

A curve was established for the conversion of microampere readings from the instrument to approximate foot candle units. The foot candle conversion data for this graph were made from readings obtained with the surface cell equipped with the flashed opal diffuser.

Data for conversion of microammeter reading to foot candle were obtained by calibrating the limnophotometer with a standard pyrheliometer. Output of the pyrheliometer, which is measured with a potentiometer, is in linear relationship to light intensity. On this basis, a rectilinear plot was established by plotting readings from a foot candle meter with comparable pyrheliometer readings. Due to the limited maximum range of the foot candle meter, the established line was extrapolated to 10,000 foot candles to include the greater radiant energy levels occurring in full sunlight. Comparative readings were then made using the pyrheliometer (indicating millivolts) and the limnophotometer (indicating microamperes) from low to high radiant energy intensities. The pyrheliometer readings were converted to equivalent foot candles from the first graph and these data plotted with comparable limnophotometer readings to establish the conversion curve shown in Figure 5.

During the course of the study, radiant energy measurements were made weekly at various water depths in drums containing sediment and in control drums. For all readings obtained from the submersed cell, the percent reduction of that obtained from the surface cell or full sunlight was calculated.

Sediment Used and Method of Determining and Maintaining Concentrations

Two types of sediment were used in the studies:

One was a commercial sodium-base montmorillonite-type bentonite, which appeared light gray in color. Petrographic analysis of this material is given in Appendix A. In the wet condition, 96 to 97 percent of the material is smaller than 44 microns, 93 to 94 percent is smaller than 5 microns, 87 to 89 percent is smaller than 0.05 microns, and 60 to 65 percent is smaller than 0.1 micron, Figure 6.

The other sediment was obtained from Angostura Reservoir, South Dakota. It was brown in color, and its petrographic analysis is given in Appendix B. In the wet condition, approximately 99 percent of the material is smaller than 40 microns, 95 percent is smaller than 10 microns, 83 percent is smaller than 5 microns, and 49 percent is smaller than 1 micron, Figure 6.

Drums were arranged as shown in Figure 7, and sediment was added to drums after premixing with a malted milk mixer. Concentrations of sediment were checked at approximately 2-day intervals. When concentrations were found to be below the desired level, additional sediment was added. Concentrations decreased as sediment settled in areas of low velocity. Graphs of concentrations maintained in drums are shown in Figures 8, 9, 10, 11, 12, and 13.

Suspended sediment concentrations were determined with a modified turbidimeter, Figure 14. A vented light eliminator, to prevent outside light from entering the area near the candle and to create a near-constant light condition around the candle, was designed and is shown in Figures 14a and 14c.

The turbidimeter (2) consists of a calibrated glass tube, a standard candle, and a spring-loaded stand and support which aline the candle and the tube. In use, the sample is poured into the glass tube until the image of the candle flame just disappears from view and the observer sees a uniformly illuminated field with no bright spots. Depth of water in the tube when the candle flame disappears is a measure of suspended sediment concentration in ppm by weight.

The turbidimeter evaluates the effect of optical properties of the sample, which causes light rays to be scattered and absorbed. As optical properties are affected by size, shape, refractive index, and transparency of the material in suspension, the turbidimeter was calibrated in parts per million by weight for each sediment.

Tests Conducted

Test 1 was conducted during the growing season of 1958. In this test, the drums were divided into two 4-drum groups. One 4-drum group contained potted ungerminated plant propagules, and the other group contained potted established vegetative cultures. One drum from each group was used as a control and contained no sediment. To cover a wide range of sediment levels, the approximate concentrations in parts per million by weight (ppm) maintained in one drum from each group were 50, 200, and 800 ppm. Graphs of concentrations maintained in the drums are shown in Figures 8 and 9. The light-gray montmorillonite-type bentonite was used as the sediment throughout the test.

Test 2 was conducted during the early 1959 growing season. Each of the eight drums contained a propagule and a vegetatively established culture of each plant species being tested. Two drums were used as control and contained no sediment. In three drums, the light-gray montmorillonite-type bentonite was maintained at concentrations of approximately 1,250, 2,500, and 5,000 ppm. In the three remaining drums, brown Angostura Reservoir sediment was maintained at concentrations of approximately 1,250, 2,500, and 5,000 ppm. Graphs of concentrations maintained in the drums are shown in Figures 10 and 11.

Test 3 was conducted during the late 1959 growing season. The drums were divided into two 4-drum groups. One group contained potted ungerminated plant propagules and the other group contained potted established vegetative cultures. One drum from each group was used as a control and contained no sediment. Angostura Reservoir sediment was added to the remaining six drums. Approximate concentrations maintained in one drum for each group were 50, 250, and 800 ppm. Graphs of concentrations maintained in each drum are shown in Figures 12 and 13.

Biological Testing

Three species of the Potamogeton genus were used as test plants in Test 1, conducted during the summer of 1958. These species were sago pondweed, P. pectinatus L.; leafy pondweed, P. foliosus Raf.; and American pondweed, P. nodosus Poir. Tests 2 and 3, conducted in 1959, utilized the same species excepting leafy pondweed, which did not develop properly during the course of the first study. Common waterweed, Elodea canadensis Michnx., was substituted because of its adaptability to cultivated situations.

Cultures were established by using vegetative propagules: (1) tubers of the sago pondweed, (2) winter buds of the American pondweed, (3) axillary winter buds of the leafy pondweed, and (4) excised stems of waterweed. These propagules were planted in 6-inch clay pots filled with topsoil.

Two types of cultures were used in the study. The first type was a vegetative mature series where propagules were planted and allowed to reach a stage of growth near vegetative maturity before being exposed to the various concentrations of suspended sediment. This required a period of 3 to 4 weeks for sago pondweed, American pondweed, and common waterweed, and 2 months for leafy pondweed. The other type was a propagule series where ungerminated or excised propagule materials were planted in the potted soil and immediately placed in the suspended sediment environment. Plants in two different stages of growth were used to determine the effects of sediment shading on pondweeds already vegetatively established, as compared to effects of sediment shading on the germination and establishment of an infestation of pondweeds.

Replications of two pots per species were used in each drum of each treated and control series, excepting Test 2. Three species were represented in the various conditions of treatment in all tests.

Plant cultures were exposed to the suspended sediment concentrations for a period of 6 weeks in the first test, 5 weeks in the second, and 4 weeks in the third. The drums were located in a position outdoors to receive full sunlight.

A continuous record of water temperature was obtained by the use of a mechanically operated thermograph. Temperature recordings were made in the control drums for each test and are shown graphically in Figures 8, 10, and 12. Temperatures of all drums varied with the ambient air.

Maximum stem length data were obtained in the initial study to differentiate between the plants' growth response to the various sediment environments. These data were found to be of limited value, so in subsequent studies, dry weights of all plant material above the ground line were obtained. Below-ground plant parts were not sampled due to the extreme difficulty encountered in separating all root and rhizome material from soil particles. It is felt that above-ground parts reflected the variations in growth response as well as total plant material. Additional tubers and winter buds were not developed on these cultures during the relatively short period of growth. Plant material was collected by species at the termination of the tests, ovendried at 62° C for 72 hours, and weighed. Visual observations were also made of the plants' general morphological development during exposure to the various sediments and concentration ranges.

RESULTS AND DISCUSSION

Radiant Energy Measurements

Results of radiant energy measurements, made during the course of the study, are graphically represented in Figures 15 and 16. Data representing measurement of the full spectrum (within sensitivity limits of the photocell) were converted to foot candle units before reducing the values to percent loss of total surface solar radiant energy. These figures would represent more accurate values as they reflect the nonlinear output characteristics of the photocells. The data representing the red and blue wave lengths were direct microampere readings reduced to percent loss of surface energy. Mathematical models of light reduction results obtained from the limnophotometer and of dry weights of plants are given in Appendix C.

A comparison of the radiant energy measurements in the two sediments shows that Angostura sediment was more efficient in reducing radiant energy levels than was bentonite at a given concentration.

As shown in Figure 15, total solar radiant energy, available at the surface, was reduced to 1 percent or less at a depth of 1 foot (30.5 cm) in all concentrations of Angostura sediment, excepting 50 ppm. Total radiant energy was reduced about 63 percent at 1-foot water depth by the filtering action of the water itself, as measured in the control situation. A further reduction of 29 percent was effected by the addition of 50 ppm of Angostura sediment at the 1-foot depth. Near-maximum shading effect was obtained at a depth of 20 cm by 250-ppm sediment level.

Spectral quality measurements tend to indicate that the red wave lengths were able to penetrate somewhat further into the sediment-laden waters than were the shorter blue wave lengths, Figure 17. Investigations by Birge and Juday (3) showed that the short wave radiation is more affected by stains and suspended matter than is radiation of longer wave lengths; whereas radiation from the red end of the spectrum is more rapidly absorbed by water and less affected by stain and suspended matter. Measurements in the control situation of this study indicated that the blue wave length energy levels were somewhat less than red wave length levels in the water depths. Apparently the water in the control contained enough stain and planktonic suspension to affect the blue wave lengths, although the differences between the two were not great.

A representative record of radiant energy measurements is shown in Table 1. This table indicates microampere readings obtained at various water depths in the control and high sediment concentration situations and corresponding foot candle values.

Biological Response

The growth response of the various plant species to shading with the two types of suspended sediments are graphically shown in Figure 18 and tabulated by individual ovendry weights in Table 2. The curves shown in Figure 18 indicate the average overall percentage weight reduction of all species and of individual species. Percent weight reduction was determined by considering the plant growth in sediment cultures to be a portion of that attained in control situations. Angostura sediment concentration of 50 ppm caused a plant growth reduction of approximately 33 percent less than that developed in the control situation. Increased growth reduction was evident as the Angostura sediment concentration increased to 1,250 ppm, where the average plant growth was approximately 90 percent less than control plants. Angostura sediment concentrations greater than 1,250 ppm were not effective in producing further significant growth reduction.

Commercial bentonite caused growth reductions of a similar trend but required concentrations greater than the field sediment to produce similar results. Data for the first tests indicated commercial bentonite concentrations of 800 ppm and less did not produce significant shading of solar radiation to significantly reduce plant growth. These data were obtained by visual observation only, and dry weight data were not obtained. Results of the initial test are shown in Table 3.

All species exhibited near-normal growth characteristics at low sediment concentration (50 ppm) in both sediments and in the control drums. As the concentrations of sediments increased, certain changes in growth characteristics became evident. Some of these characteristics were elongation of stems in internodal areas, basal submersed leaves and stems became chlorotic. Also, changes in the development of chlorophyll and other photosynthetic pigments were noted in upper submersed leaves.

Sago pondweed was morphologically modified more than the other species. As the shading effect became greater, growth characteristics typifying apical dominance were pronounced. In sediment concentrations of 2,500 and 5,000 ppm, leaf and stem tissue were becoming extremely chlorotic at the termination of the test.

Sago pondweed appeared to be the least shade tolerant of all species tested and waterweed the most tolerant of shading. These differences are due in part to the variation in leaf area, waterweed having considerably more total leaf area. Stem elongation and pigmentation changes observed during these tests may be a response to the decrease in available radiant energy of the complete visible and near-visible spectrum or specific portions of that spectral range. Interpretation of these specific cause and effect factors is beyond the scope of the study and would require further extensive laboratory investigations.

The photographs of plant specimens in Figures 19 and 20 show some typical responses to shading by suspended sediments.

CONCLUSIONS

Data obtained under the conditions described in this report indicate that suspended sediments have a considerable effect on reducing the intensity and spectral quality of solar radiant energy penetrating sediment-laden waters. These effects vary considerably with sediment type and become more pronounced as sediment concentration increases.

Submersed aquatic plants' response to this shading effect varied somewhat with the species tested, but in general, data from this study indicate that low concentrations (50 to 100 ppm) of suspended sediment create sufficient shading to produce some growth reductions of submersed aquatic plants. This amount of growth reduction would not be considered critical to the extended survival ability of the plants. Sediment concentrations greater than 1,250 ppm would be necessary to cause plant growth reductions that might be considered critical to the plants' ability to survive.

In the authors' opinion, maintaining a concentration of fine sediment of 1,250 ppm by weight in most canals would appear generally infeasible. A field study would be necessary to determine any possibility of control for each canal.

This was a limited study in which only 3 species of weeds and 2 types of sediment were tested at 6 levels of concentrations.

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Table 1

Representative limnophotometer readings taken on July 1, 1959, from 9:30 to 11 a.m. on a cloudless day. Corresponding approximate foot candle values indicated. Instrument readings indicated in microamperes. Initial readings indicate water depth where first measurable light occurred ranging from 0 to 0.2 microamperes.

ACCESSORY EQUIPMENT USED OVER CELLS

Sediment type and concentration	Opal glass diffuser					Opal diffuser and red filter			Opal diffuser and blue filter		
	Surface cell		Submersed cell		Water depth, cm	Surface cell	Submersed cell	Water depth, cm	Surface cell	Submersed cell	Water depth, cm
	Microamps	Foot candles	Microamps	Foot candles		Microamps	Microamps		Microamps	Microamps	
5,000 ppm	7,200	9,620	Initial	--	26	1,050	Initial	19	700	Initial	8
Bentonite	7,200	9,620	192	75	10	1,050	35	10			
2,500 ppm	7,200	9,620	Initial	--	41	1,250	Initial	32	700	Initial	17
Bentonite	7,200	9,620	105	42	20	1,250	19	20			
1,250 ppm	7,200	9,620	Initial	--	62	1,350	Initial	48	700	Initial	25
	7,200	9,620	77	30	31	1,350	203	10	700	29	10
	7,200	9,620	275	116	20						
	7,200	9,620	1,375	120	10						
Control drum	7,200	9,620	550	240	62	1,050	91	62	600	49	62
	7,200	9,620	4,840	4,100	31	1,050	700	31	600	385	31
	7,200	9,620	5,280	5,100	20	1,050	770	20	600	420	20
	7,200	9,620	5,720	6,180	10	1,050	840	10	600	490	10
	7,200	9,620	5,720	6,180	5	1,050	840	5	600	560	5
1,250 ppm	7,200	9,620	Initial	--	22	1,100	Initial	17	650	Initial	10
Angostura	7,200	9,620	19	7	10	1,100	20	8			
	7,200	9,620	275	116	5						
2,500 ppm Angostura	7,200	9,620	Initial	--	10	1,100	Initial	10	650	Initial	4
5,000 ppm Angostura	7,200	9,620	Initial	--	4	1,200	Initial	4	700	Initial	2

Table 2

DRY WEIGHTS OF PLANT MATERIAL
EXPOSED TO SUSPENDED SEDIMENTS
(Plant Material Sampled Above Soil Line)

Oven dried 62° C--72 hours   Average weight two replications

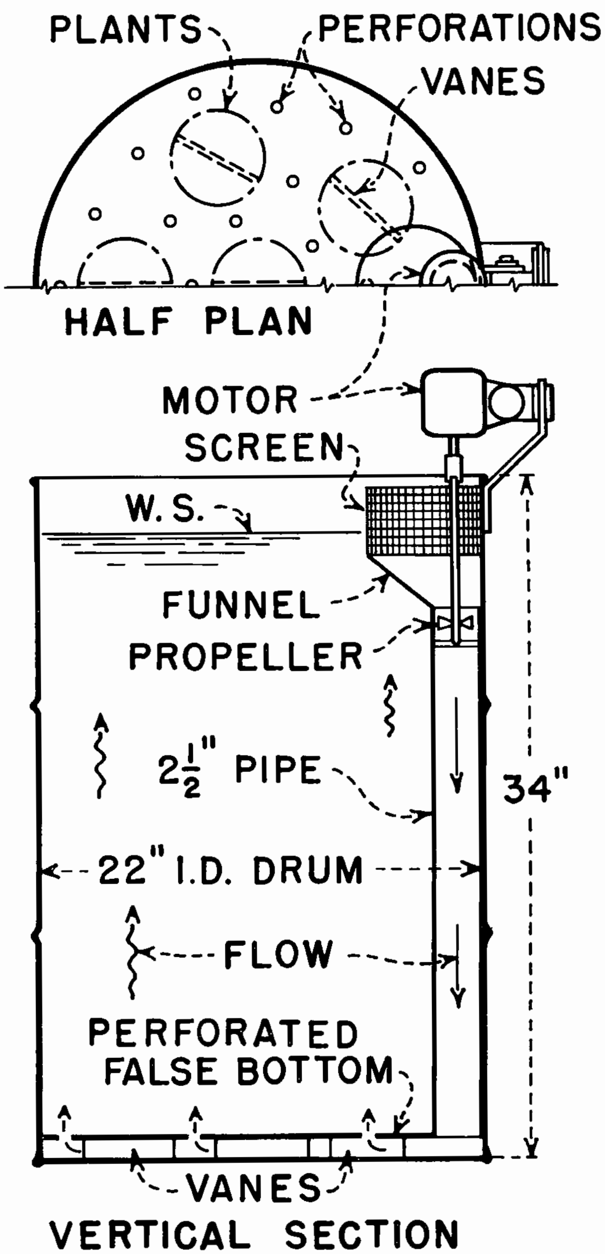
Type of culture	Sediment and concentration	Species (weight in grams)		
		P. pectinatus	P. nodosus	E. canadensis
Propagule	Control	0.089	1.465	1.212
Propagule	Angostura, 50 ppm	0.234	1.490	0.653
Propagule	Angostura, 250 ppm	0.611	0.760	0.363
Propagule	Angostura, 800 ppm	0.096	0.468	0.218
Established	Control	1.349	2.877	7.399
Established	Angostura, 50 ppm	1.188	1.814	4.753
Established	Angostura, 250 ppm	0.097	0.989	3.030
Established	Angostura, 800 ppm	0.074	0.504	1.719
Propagule	Control	8.018	1.086	0.471
Propagule	Angostura, 1,250 ppm	0.198	0	0.193
Propagule	Angostura, 2,500 ppm	0.085	0	0.055
Propagule	Angostura, 5,000 ppm	0.116	0.085	0.049
Established	Control	3.443	2.149	4.298
Established	Angostura, 1,250 ppm	0.081	1.05	0.925
Established	Angostura, 2,500 ppm	0.090	0.453	1.017
Established	Angostura, 5,000 ppm	0.365	0.065	0.928
Propagule	Control	1.229	0.664	1.071
Propagule	Bentonite, 1,250 ppm	0.542	0.400	0.041
Propagule	Bentonite, 2,500 ppm	0.222	0.077	0.124
Propagule	Bentonite, 5,000 ppm	0.162	0.017	0.091
Established	Control	4.954	5.483	4.705
Established	Bentonite, 1,250 ppm	3.933	1.864	0.812
Established	Bentonite, 2,500 ppm	0.638	0.687	0.907
Established	Bentonite, 5,000 ppm	0.247	0.112	1.273

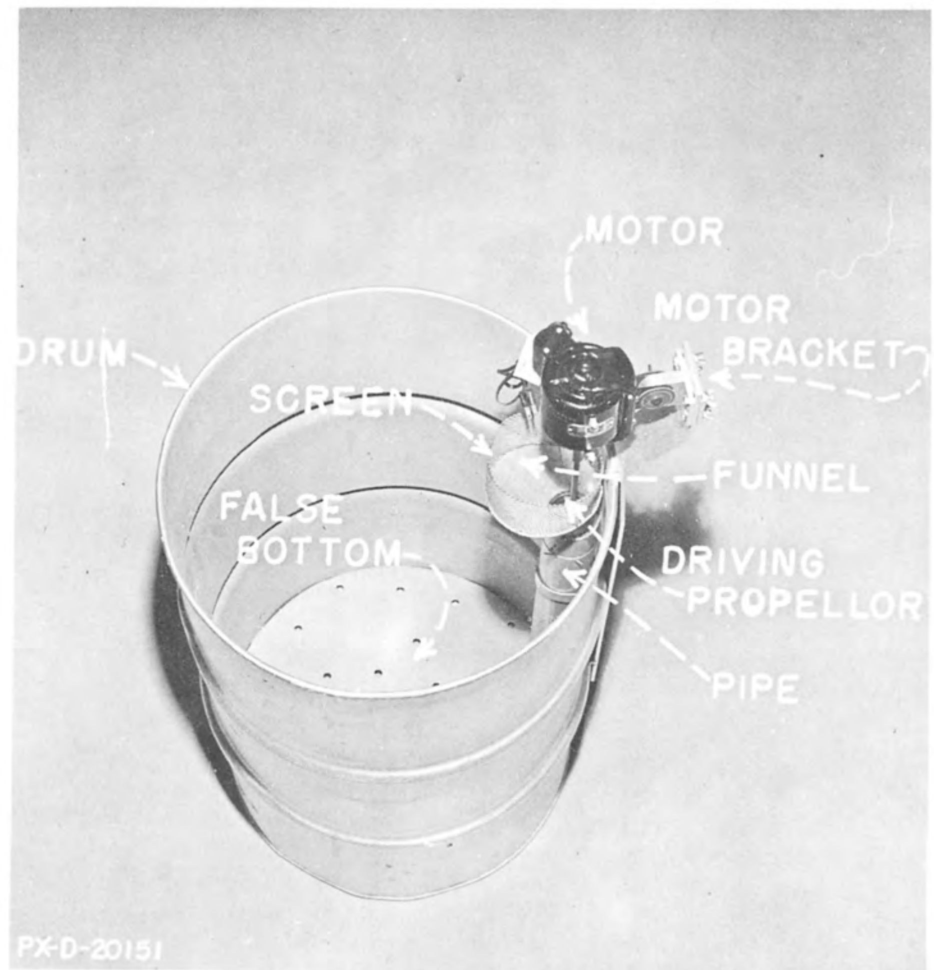
Table 3

EFFECTS OF SHADING BY VARIOUS CONCENTRATIONS OF COMMERCIAL SODIUM BENTONITE SEDIMENT ON CERTAIN POTAMOGETON SPECIES (Test 1)

Culture type	Drum No.	Sediment conc	P. pectinatus	Growth*	P. nodosus	Growth*	P. foliosus	Growth*
			Species of plants					
Propagule culture	1	Control	Normal growth, some chlorotic and necrotic tissue, not flowering	11 12	Normal growth, not flowering	29 18	Small amount of growth, not fruiting	7 8
Propagule culture	2	50 ppm	Normal growth, not flowering	14 17	Normal growth, not flowering	24 24	Stems and leaves, very fine, not fruiting	6 7
Propagule culture	3	200 ppm	Normal growth, somewhat chlorotic, flowering	25 26	Normal growth, emergent leaves, slight elongation of lower portion of stems, not flowering	31 31	Very little vegetative growth, leaves and stems very fine	4 6
Propagule culture	4	800 ppm	Normal growth, excepting elongation of lower portion of stems, flowering	29 29	Normal growth, one pot slightly chlorotic, abnormal pigmentation, not flowering	30 30	Propagules did not develop	0 0
Vegetatively established culture	5	Control	Normal growth, mature stage of growth, not flowering	14 13	Normal growth, some necrosis of emergent leaves, not flowering	26 24	Culture mature and fragmenting, some regrowth, not flowering	15 10
Vegetatively established culture	6	50 ppm	Normal growth, fruiting	23 20	Normal growth, submersed leaves, exhibited abnormal pigmentation, fruiting	33 32	Small amount of growth, not flowering	14 11
Vegetatively established culture	7	200 ppm	Normal growth, not flowering	22 20	Normal growth, submersed leaves, exhibited abnormal pigmentation, fruiting	32 30	Mature stage of growth, not flowering	18 12
Vegetatively established culture	8	800 ppm	Normal growth, one culture not well developed, not flowering	29 13	Normal growth, submersed leaves, exhibited abnormal pigmentation, elongated internodes on lower stem, fruiting	35 31	One culture normal, one culture did not survive, not flowering	28 0

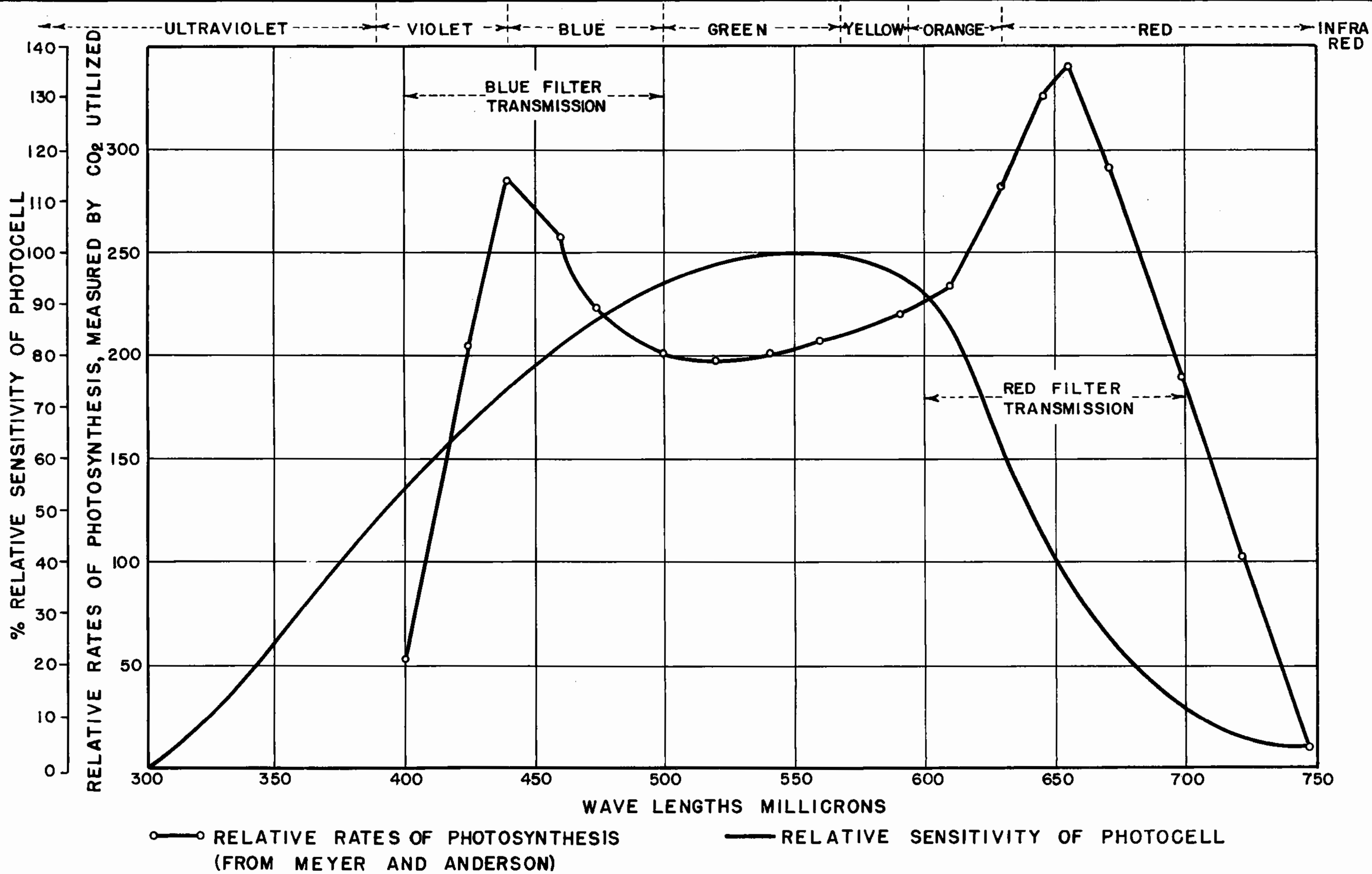
*Designates total terminal growth in inches for each replication of potted plants following exposure to concentrations of suspended sediment for a period of 6 weeks.





APPARATUS TO HOLD
FINE SEDIMENT IN SUSPENSION

Limnophotometer assembly, consisting of two photocells, one a submersible unit (2), the other a surface unit (5), a control box with appropriate instrumentation (4), and colored filters (3).



SPECTRAL RANGE

1. RELATIVE RATES OF PHOTOSYNTHESIS
2. BLUE AND RED FILTERS
3. LIMNOPHOTOMETER PHOTOCELLS

FIGURE 3
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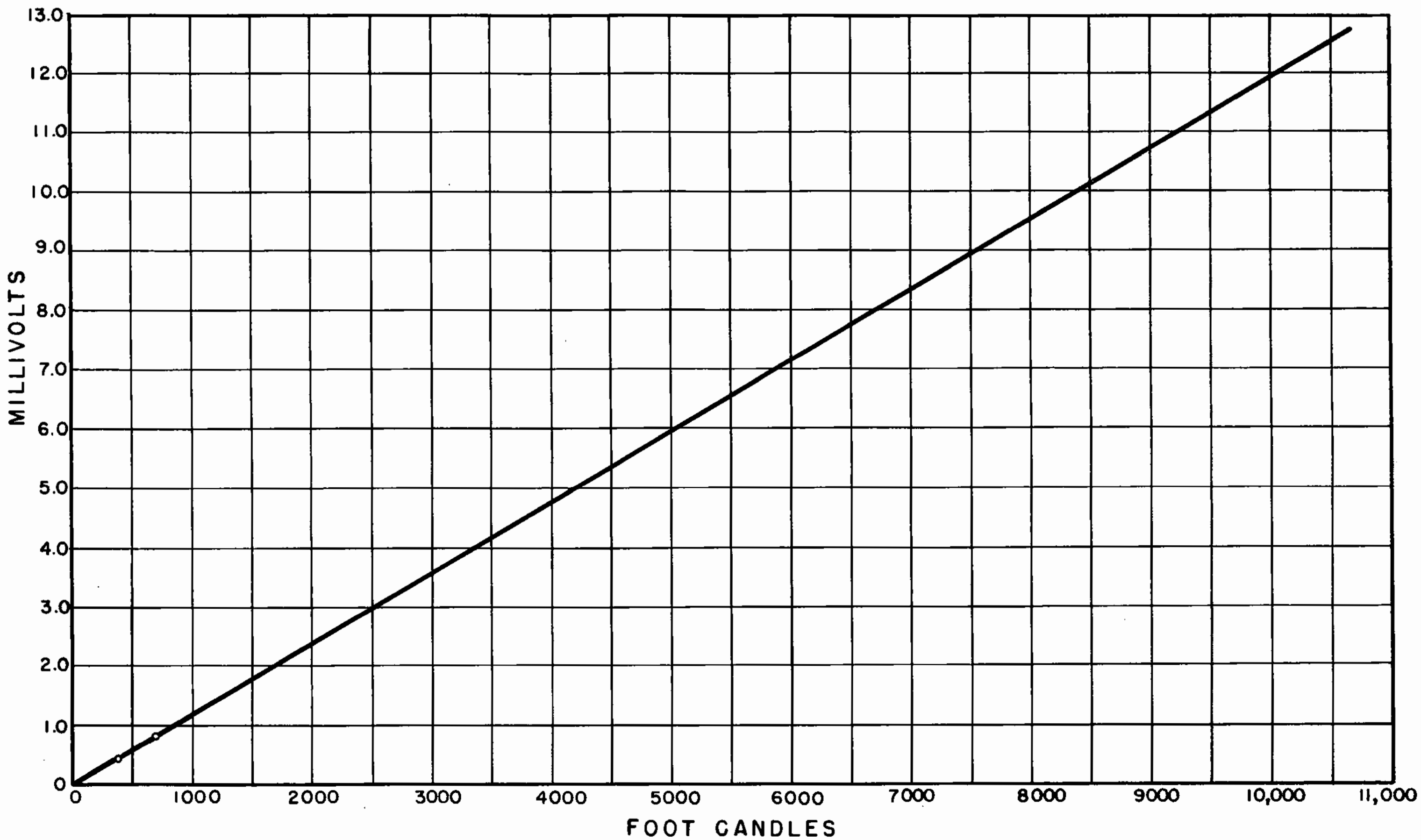
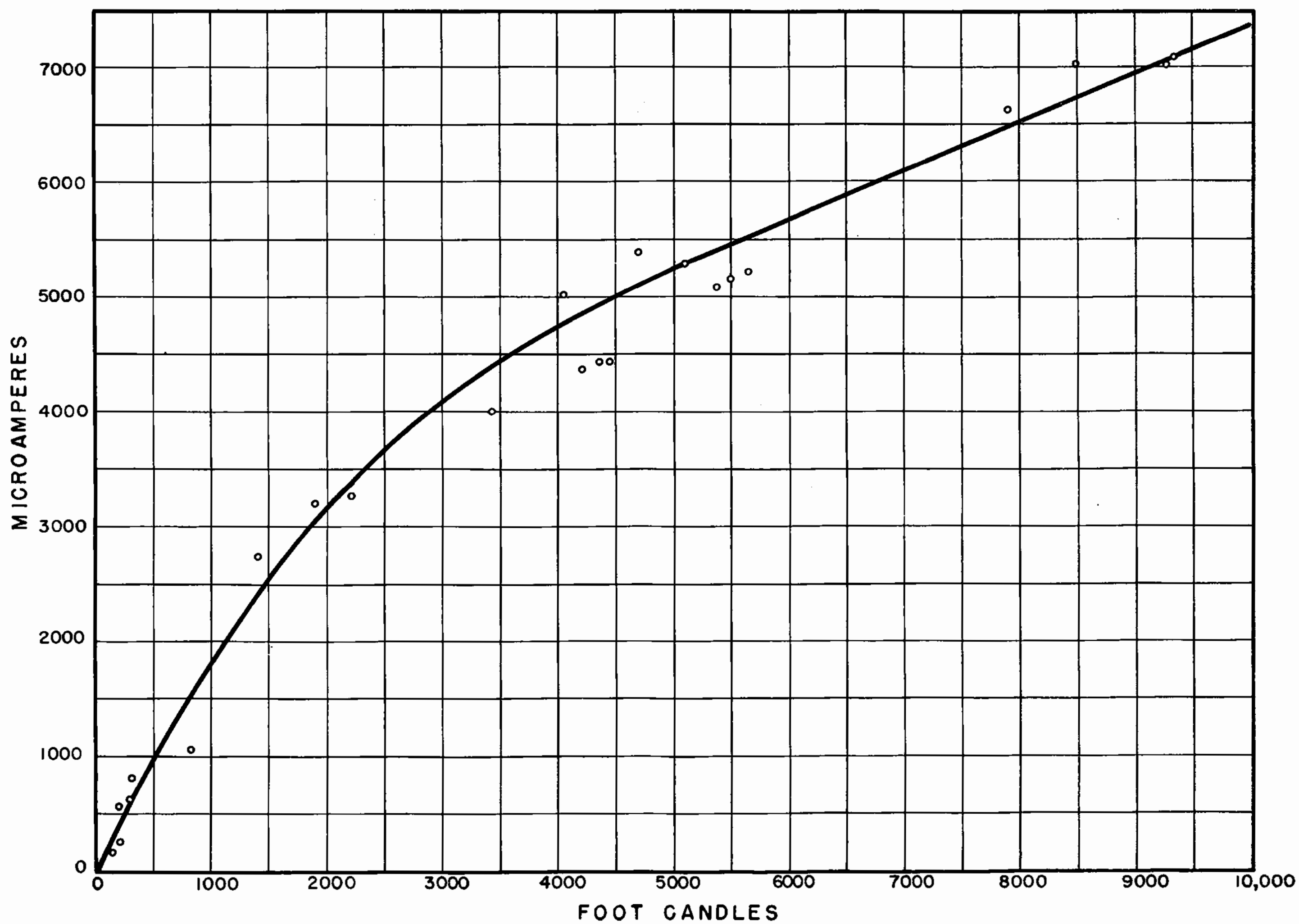


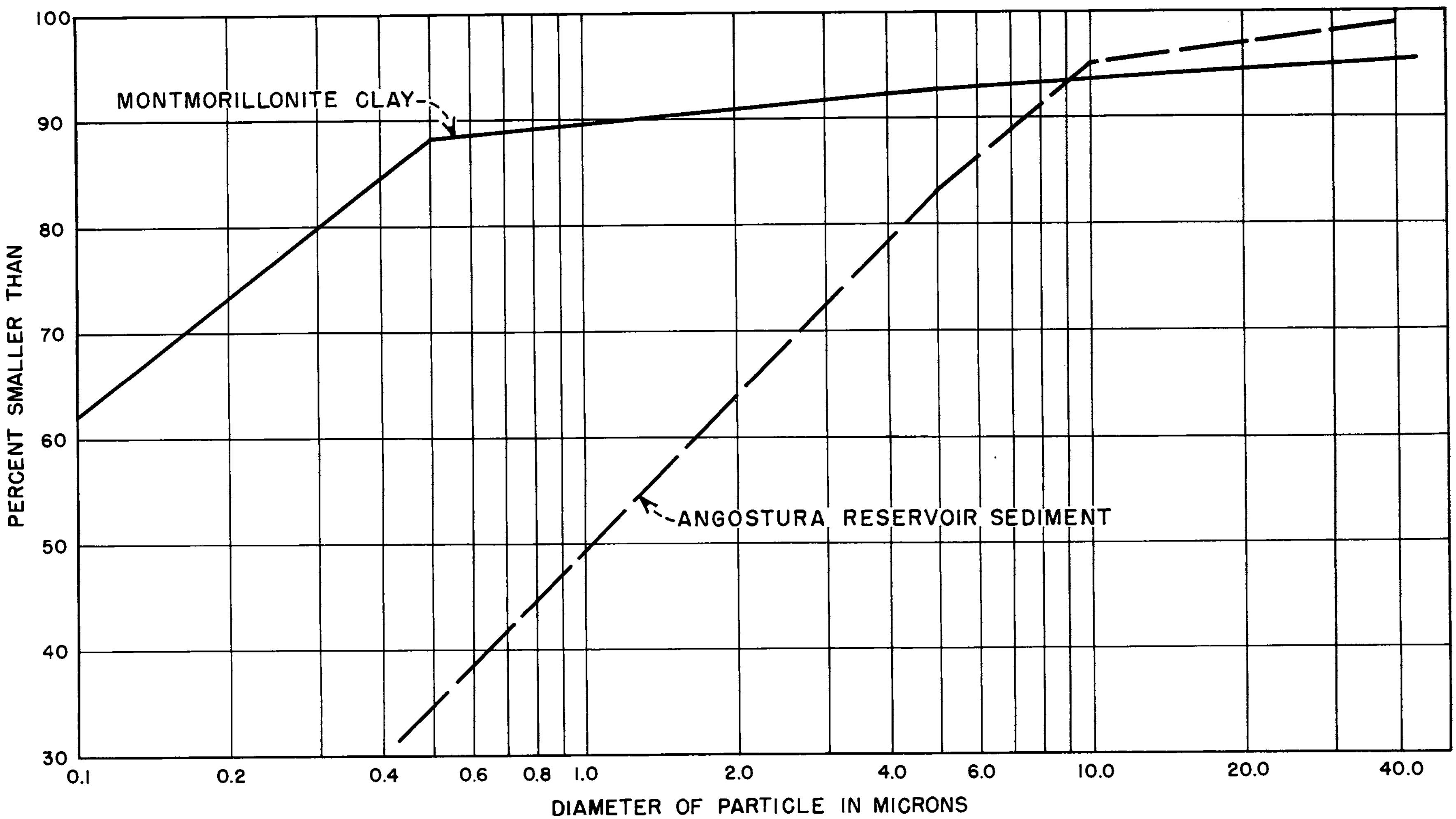
CONVERSION OF MILLIVOLTS TO FOOT CANDLE UNITS
(MILLIVOLT READING OBTAINED FROM PYRHELIOMETER)

FIGURE 4
REPORT GEN. 27



CONVERSION OF MICROAMPERES TO FOOT CANDLE UNITS
(MICROAMPERE READING OBTAINED FROM LIMNOPHOTOMETER)

FIGURE 5
REPORT GEN. 27



GRADATION - WET CONDITION OF SEDIMENTS

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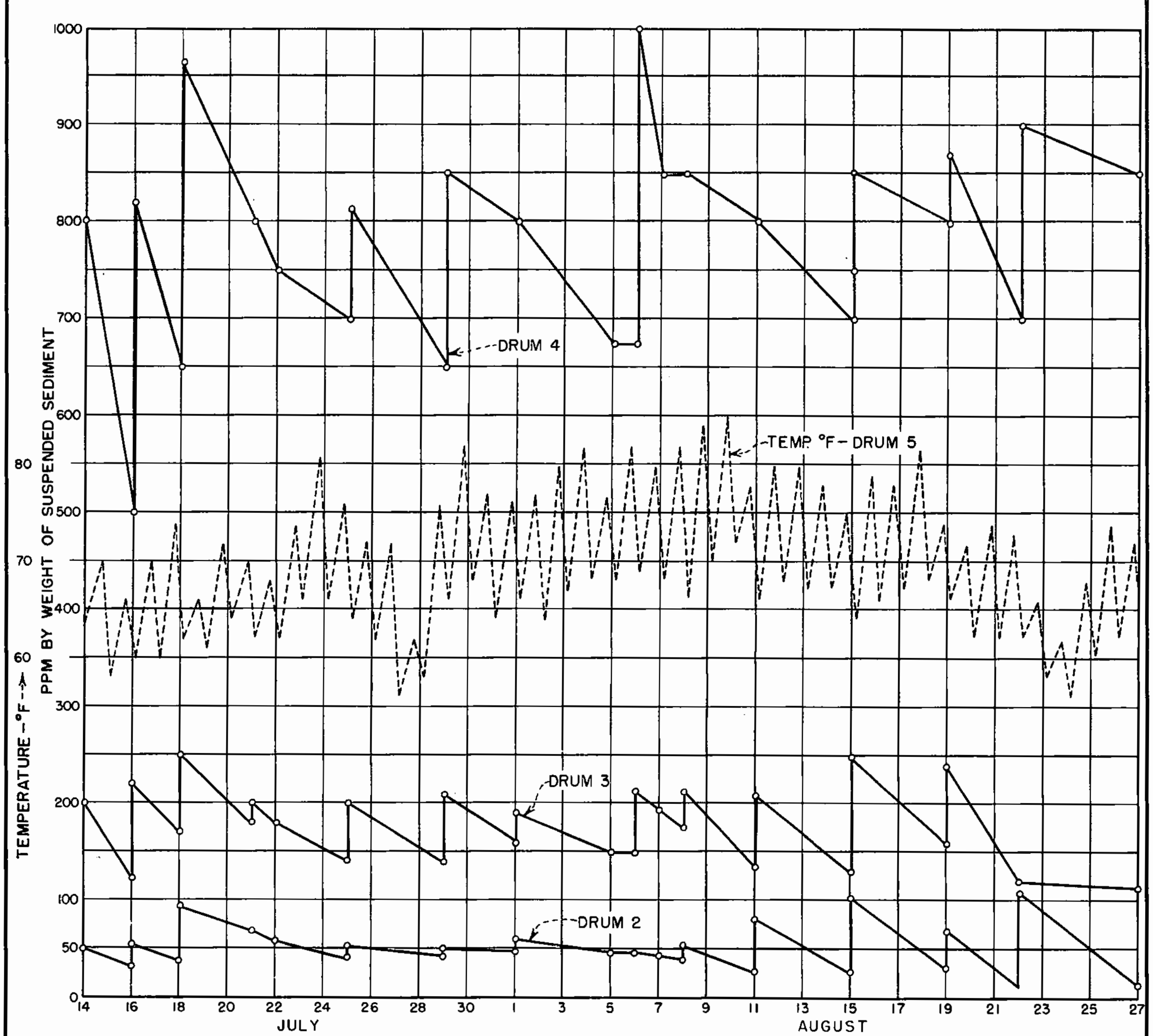
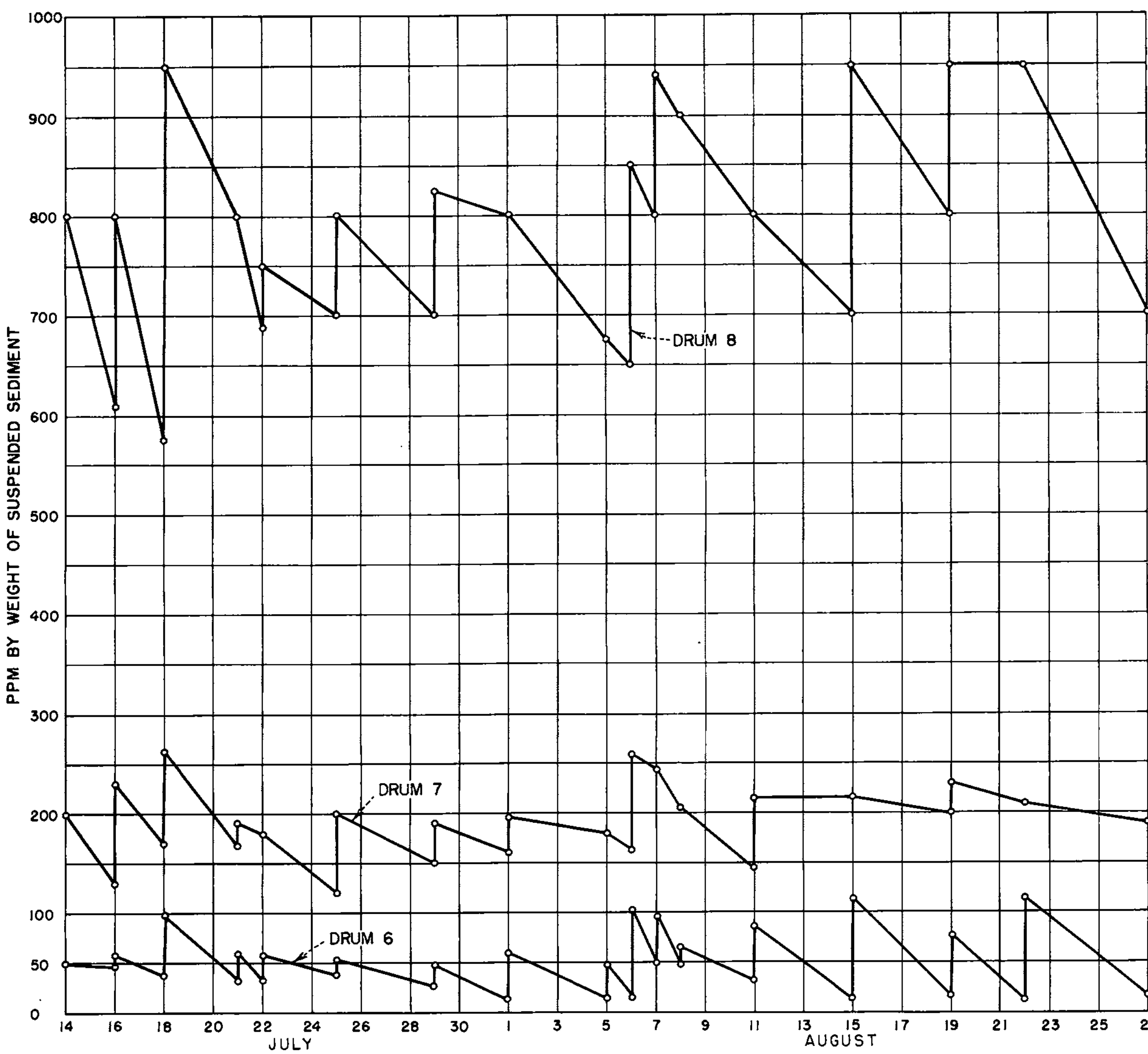
FIGURE 6
REPORT GEN. 27

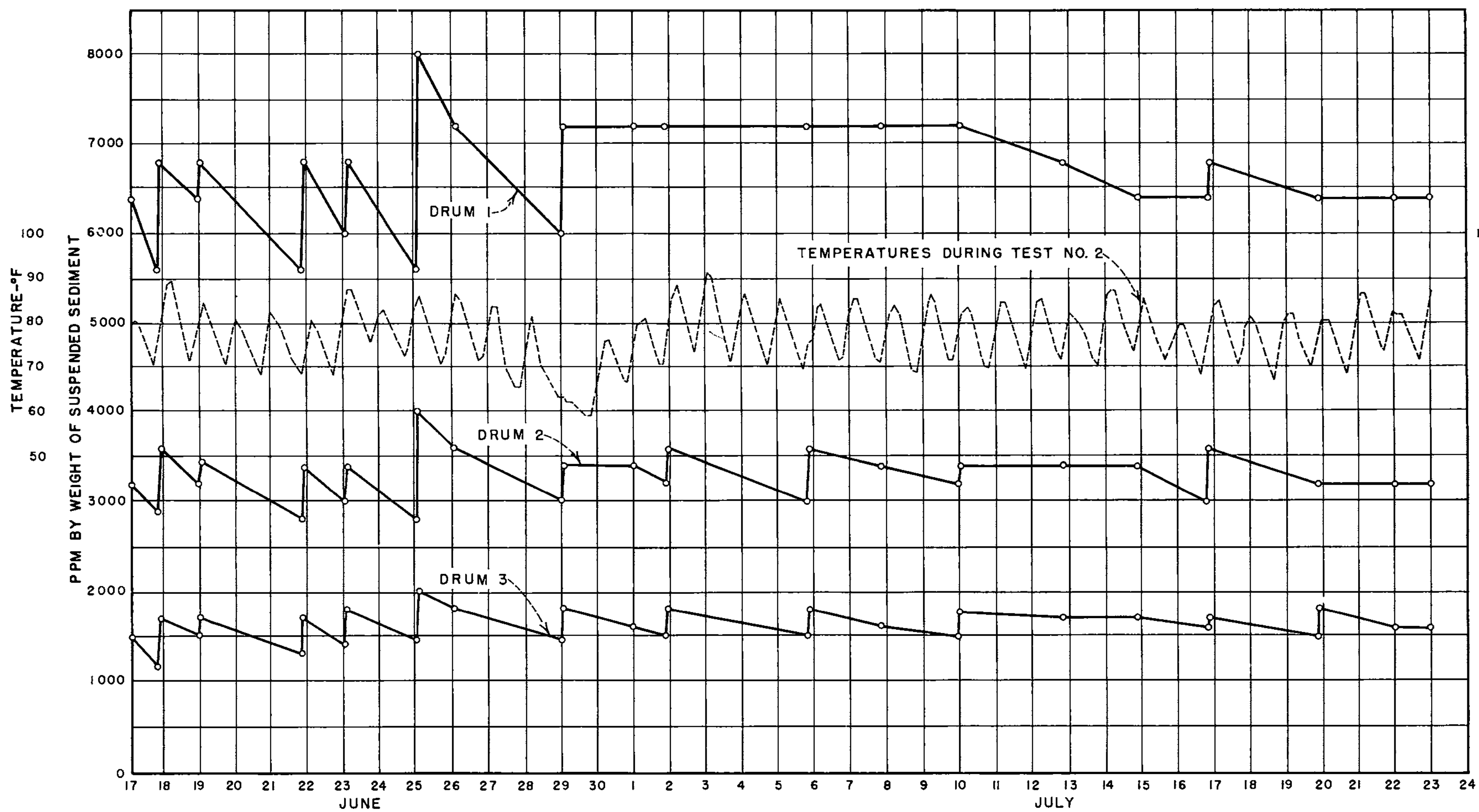
ARRANGEMENT OF DRUMS DURING TESTS



SEDIMENT CONCENTRATIONS AND WATER TEMPERATURES
IN DRUMS CONTAINING PROPAGULES - TEST I

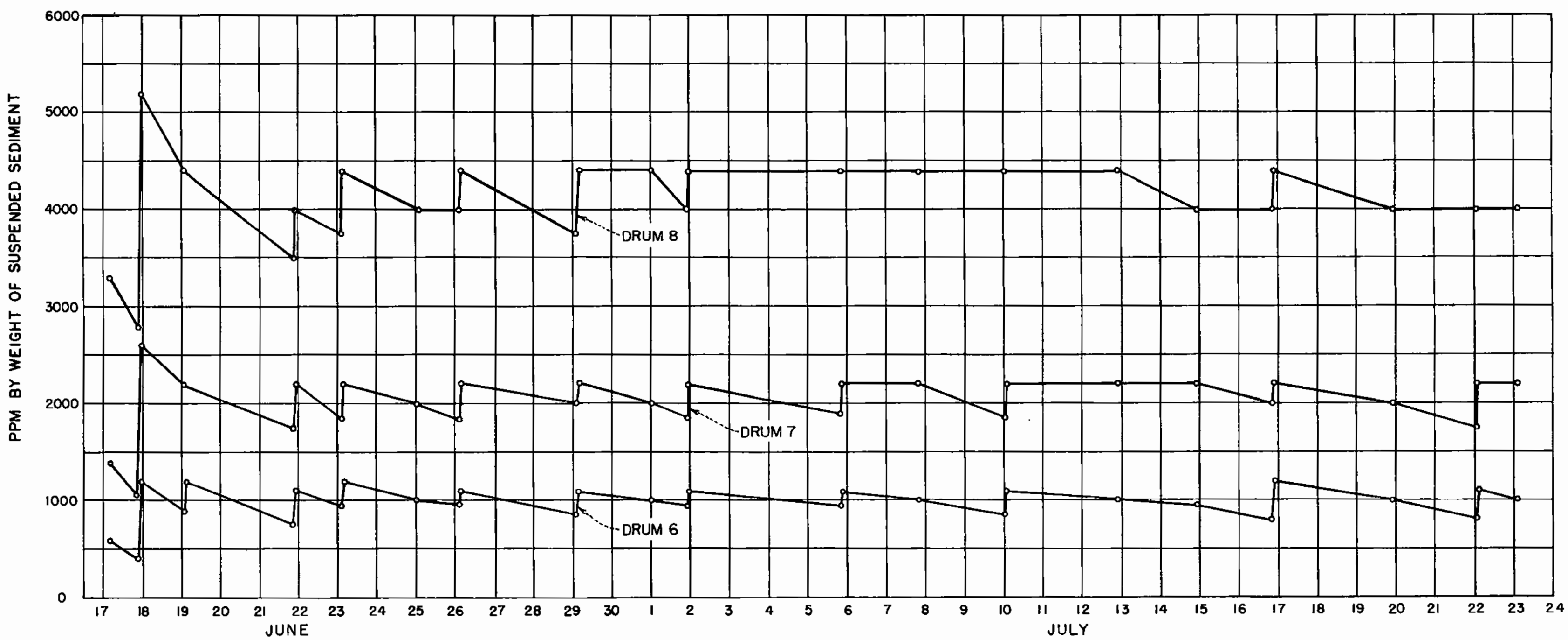


SEDIMENT CONCENTRATIONS IN DRUMS
CONTAINING ESTABLISHED CULTURES—TEST I



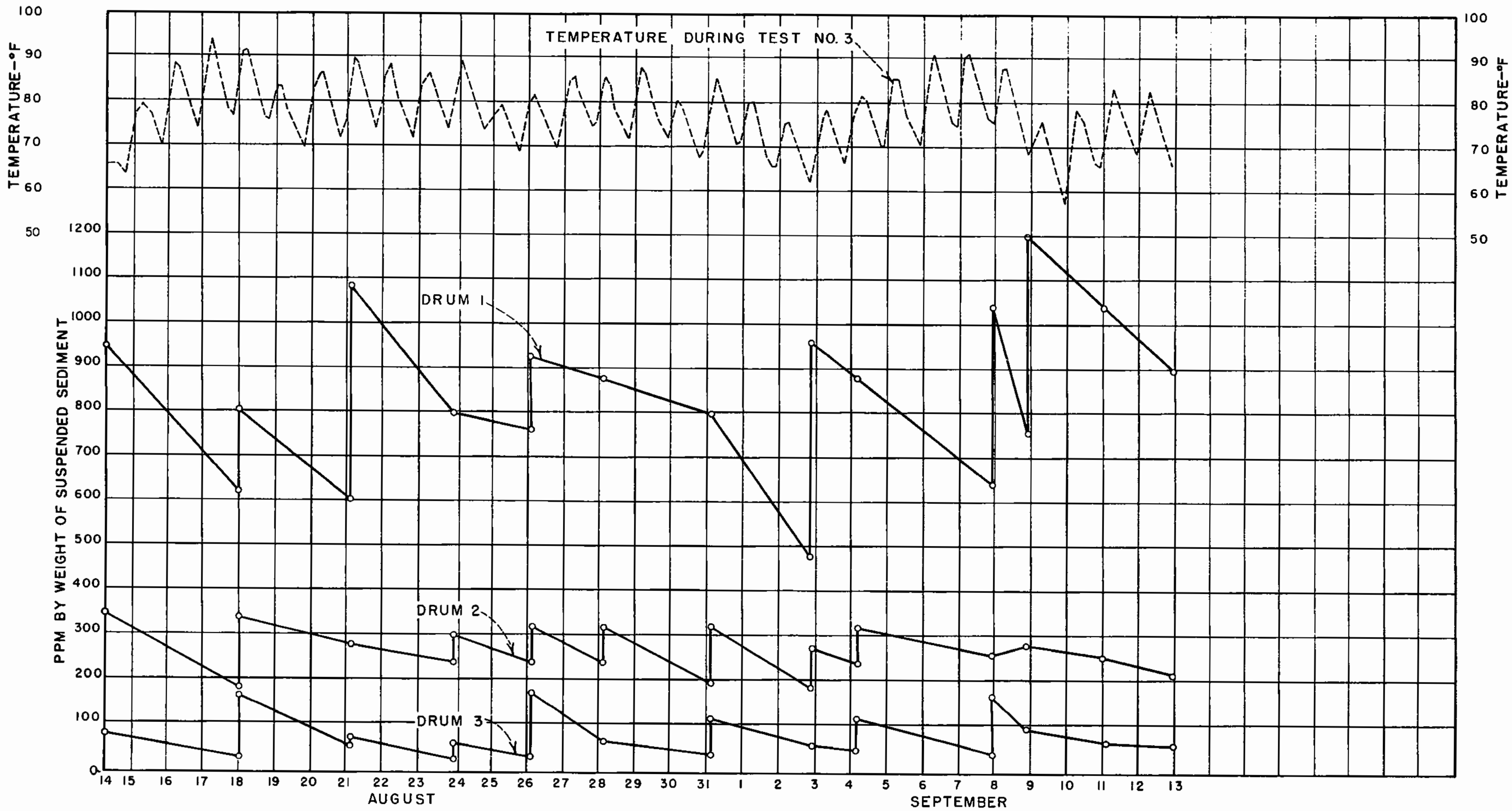
SEDIMENT CONCENTRATIONS AND WATER TEMPERATURE
IN DRUMS CONTAINING MONTMORILLONITE SEDIMENT—TEST 2

FIGURE 10
REPORT GEN. 27



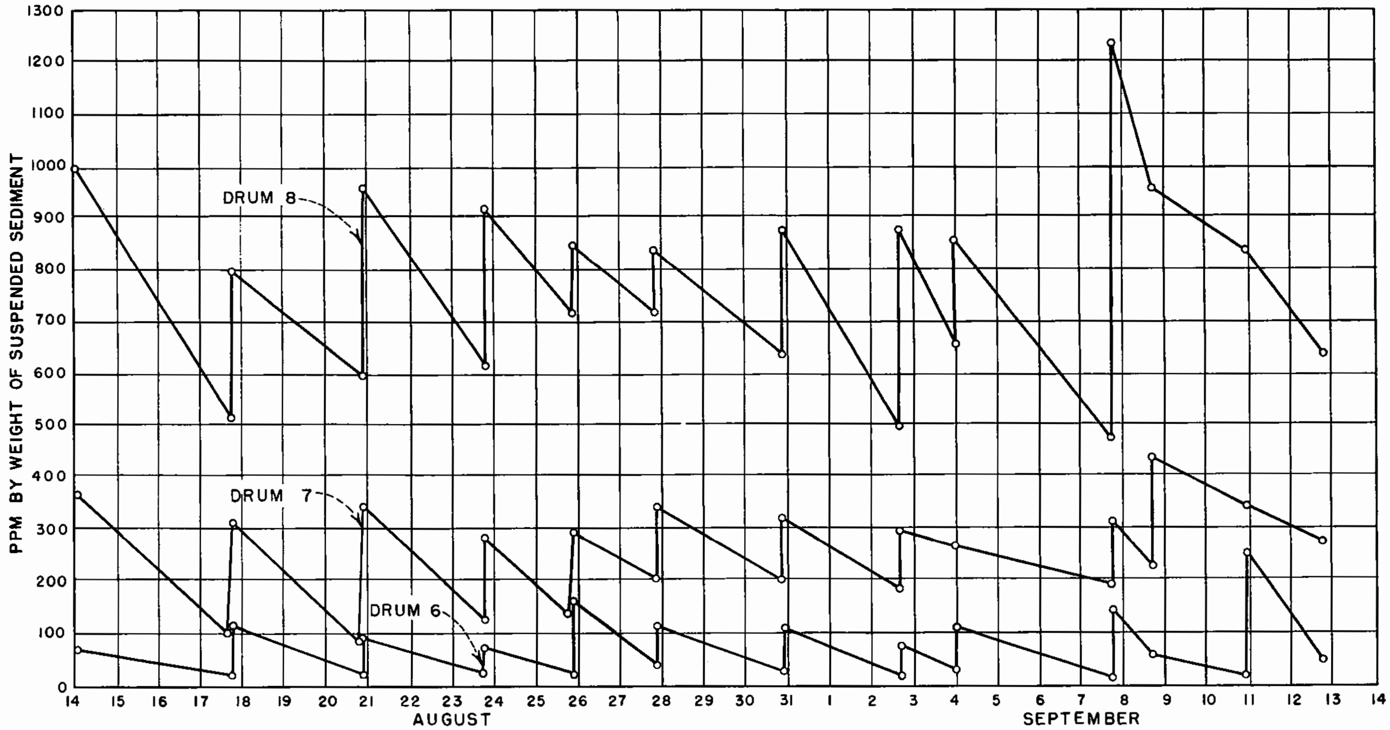
SEDIMENT CONCENTRATIONS IN DRUMS
CONTAING ANGOSTURA SEDIMENT—TEST 2

FIGURE 11
REPORT GEN. 27



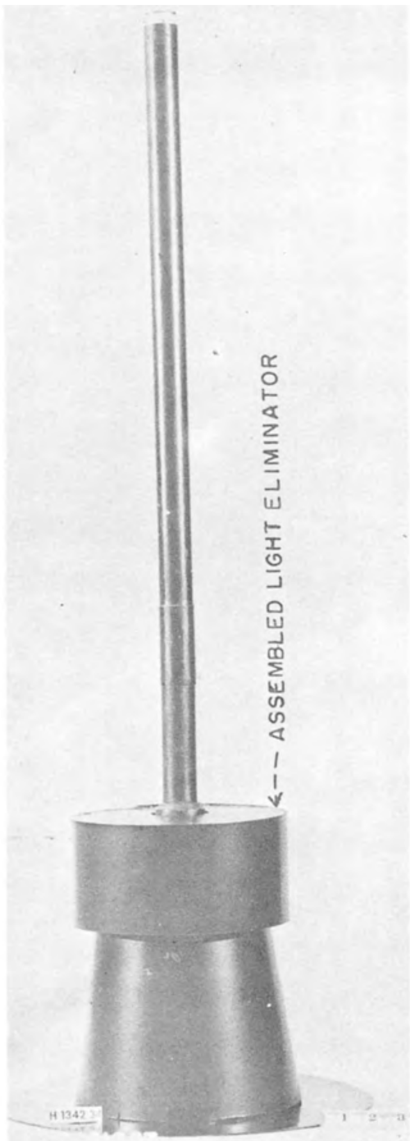
SEDIMENT CONCENTRATIONS AND WATER TEMPERATURE
IN DRUMS CONTAING WINTER BUDS AND ANGOSTURA SEDIMENT—TEST 3

FIGURE 12
REPORT GEN. 27

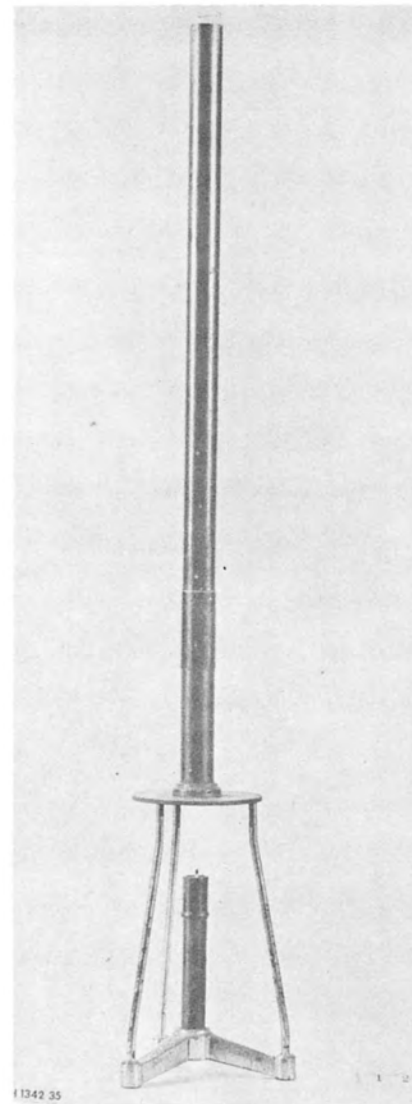


SEDIMENT CONCENTRATIONS IN DRUMS CONTAINING
ESTABLISHED PLANTS AND ANGOSTURA SEDIMENT—TEST 3

FIGURE 13
REPORT GEN. 27



(a)



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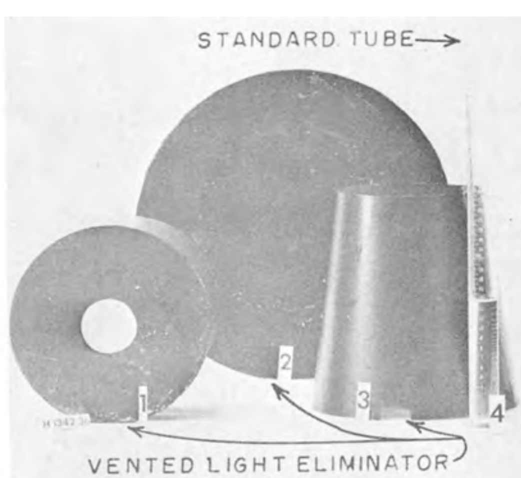
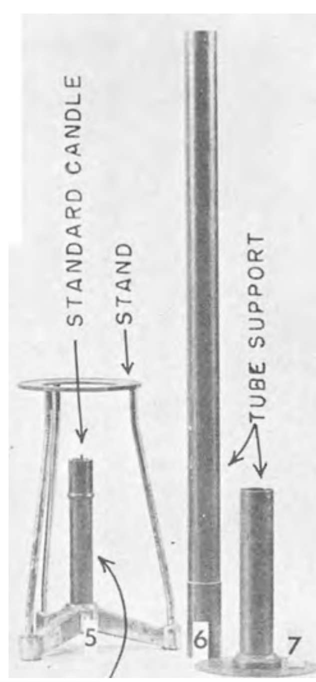
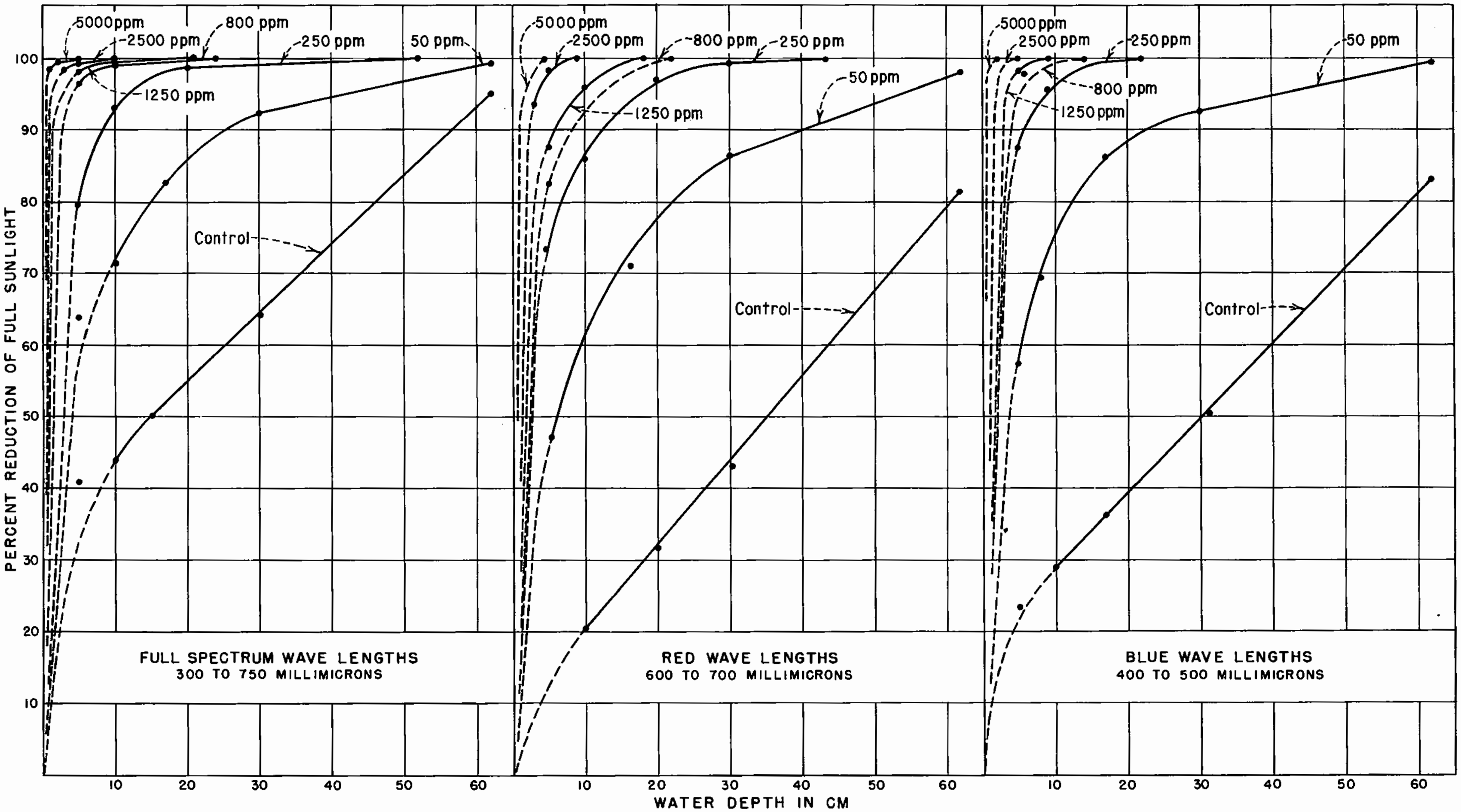




Jackson Turbidimeter Equipment

612



Note: Extreme ends of curves denote maximum depth of measurable light

PERCENT REDUCTION OF FULL SUNLIGHT
PRODUCED BY ANGOSTURA SEDIMENTS

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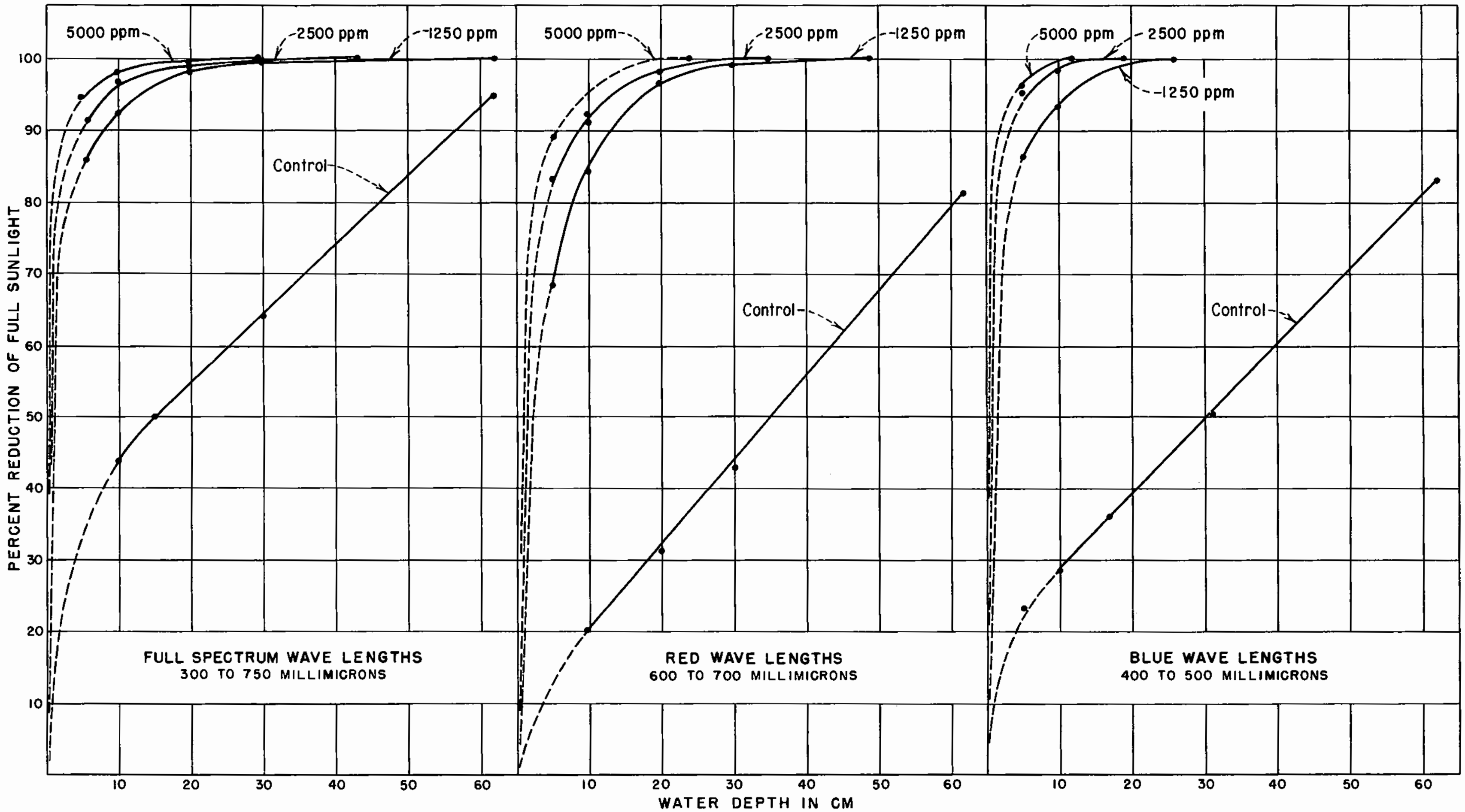
FIGURE 15
REPORT GEN. 27

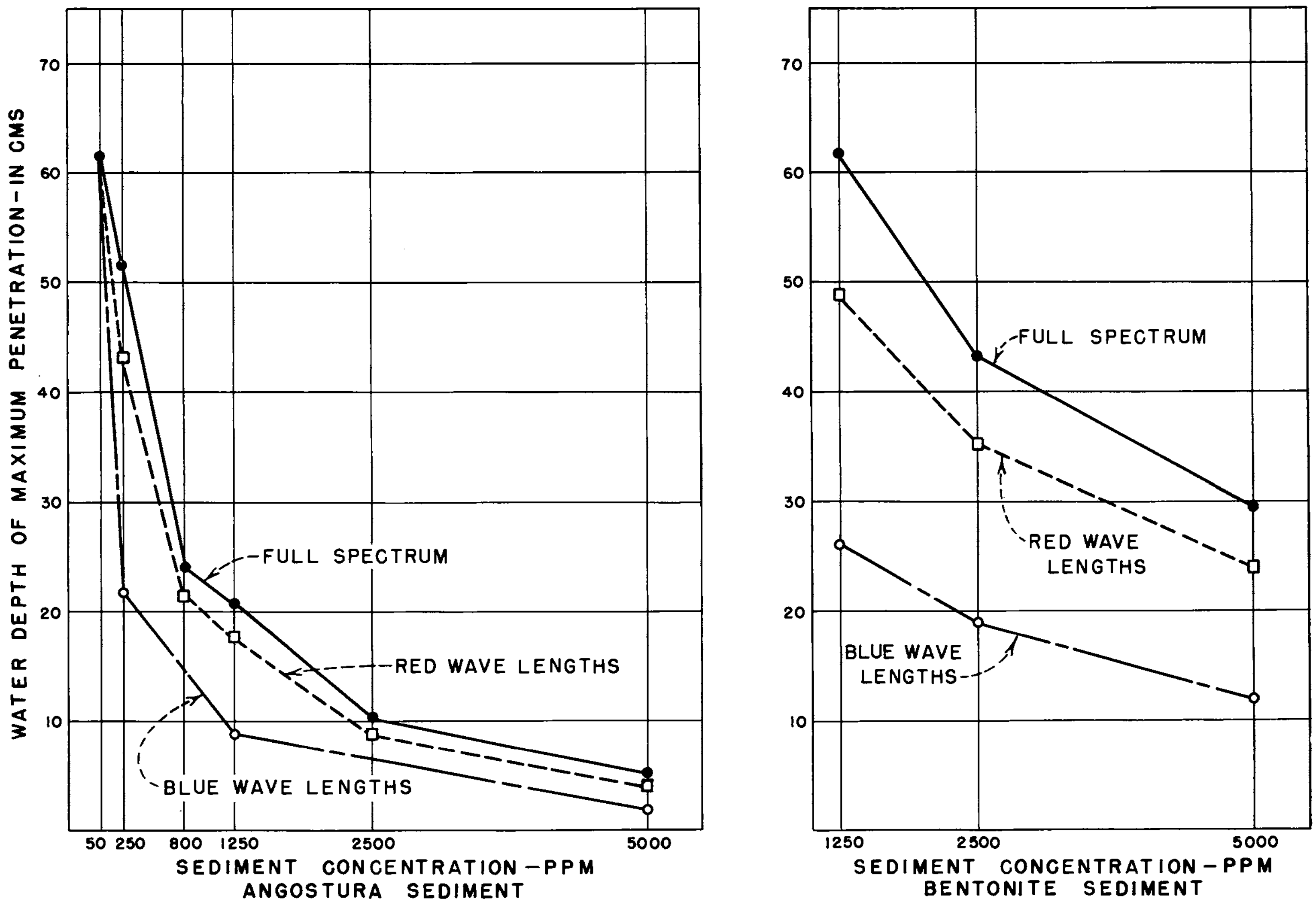


Note: Extreme ends of curves denote maximum depth of measurable light

PERCENT REDUCTION OF FULL SUNLIGHT PRODUCED BY SODIUM BENTONITE SEDIMENTS

APRIL 1960

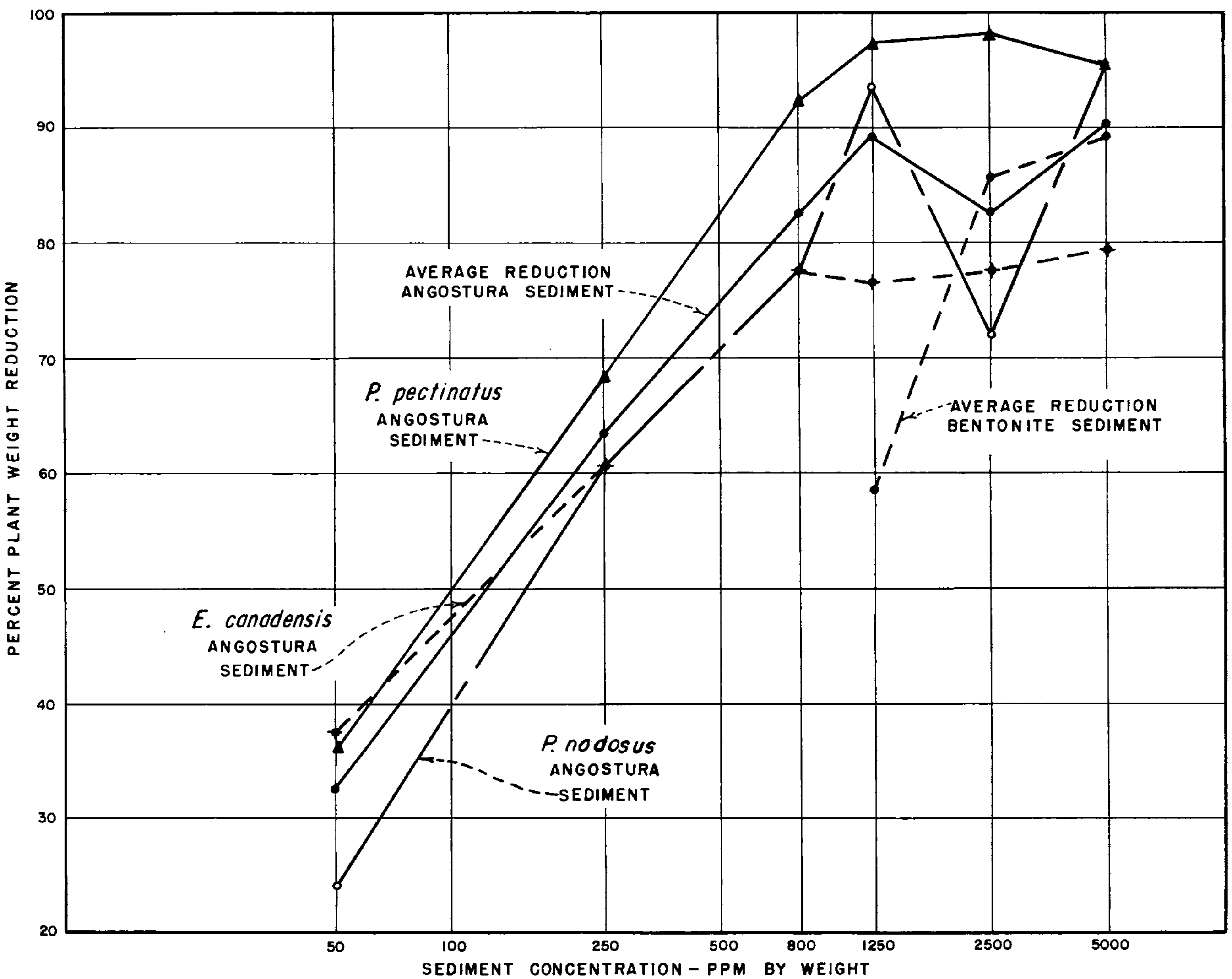
FIGURE 16
REPORT GEN. 27



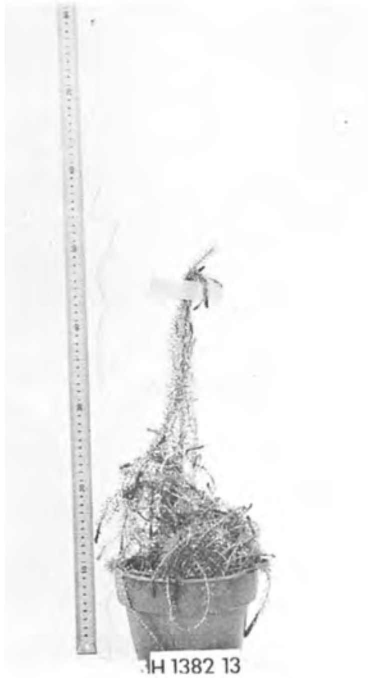
AVERAGE MAXIMUM PENETRATION DEPTH
OF LIGHT INTO SEDIMENT LADEN WATER

APRIL 1960

FIGURE 17
REPORT GEN. 27

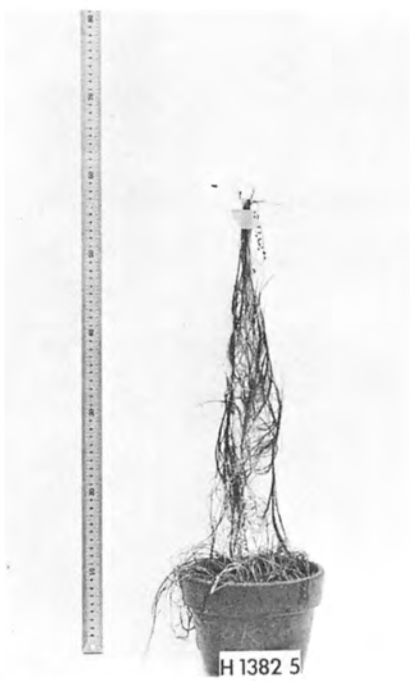


PERCENT PLANT WEIGHT REDUCTION
PRODUCED BY SUSPENDED SEDIMENTS



Growth of an established culture of Elodea after 4 weeks in a control drum

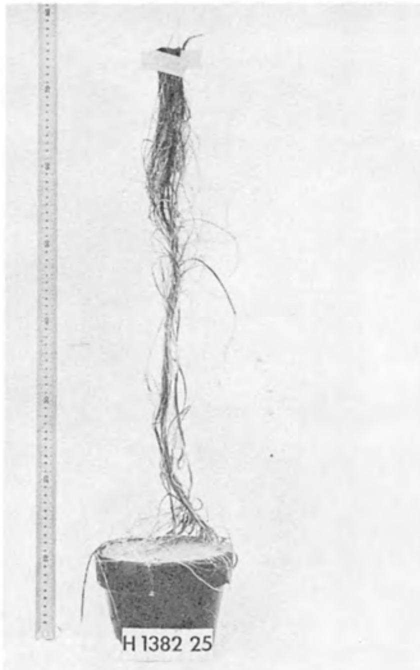
Growth of an established culture of Elodea after 4 week exposure to 5000ppm conc. of Angostura sediment



Growth of P. pectinatus propagules after 4 weeks in a control drum

Growth of P. pectinatus propagules after a 4 week exposure to 5000ppm conc. of Angostura sediment

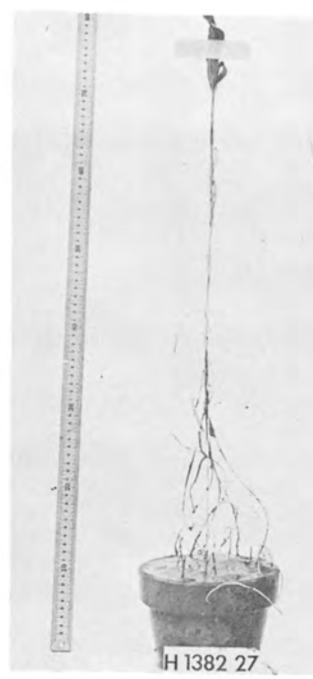
Typical growth of submersed aquatic plants exposed to shading produced by suspended sediments



Growth of an established culture of P. pectinatus after 4 week exposure to 1250ppm conc. of bentonite

Growth of P. pectinatus propagules after a 4 week exposure to 2500ppm conc. of Angostura sediment

Growth of an established culture of P. nodosus after 4 weeks in a control drum



Growth of an established culture of P. nodosus after 4 week exposure to 2500ppm conc. of Angostura sediment

Typical growth of submersed aquatic plants exposed to shading produced by suspended sediments

APPENDICES

APPENDIX A

PETROGRAPHIC DESCRIPTION OF COMMERCIAL SODIUM-BASE BENTONITE SEDIMENT

The bentonite is light gray in color with a slight greenish cast. Particles are generally subrounded in shape. Size of the particles ranges from less than 0.01 mm to 1 mm in diameter, averaging about 0.1 mm.

X-ray diffraction analysis of the bentonite indicates that it is composed essentially of sodium montmorillonite clay, minor amounts of feldspar (including both potash and plagioclase feldspar), quartz, and trace amounts of calcite. Clay-staining techniques were employed, and a montmorillonite color reaction was obtained on the sample. The estimated quantitative analysis of the bentonite, based upon microscopic observation and X-ray diffraction line intensities, is as follows:

Montmorillonite	94 percent
Feldspar (plagioclase and potash)	4 percent
Quartz	2 percent
Calcite	Trace

APPENDIX B

PETROGRAPHIC EXAMINATION OF SEDIMENT FROM ANGOSTURA RESERVOIR

X-ray diffraction and differential thermal analyses tests were conducted on the clay sample. The sample of clay was found to have the following approximate mineralogical composition:

Calcium beidellite	40-60 percent
Quartz and chalcedony	15-20 percent
Illite and mica	10-15 percent
Kaolinite	5-10 percent
Feldspar	2 percent
Calcite	5 percent
Organic matter	Small amount

The calcium beidellite is a montmorillonite-type clay which contains frequent silica-for-alumina substitutions in the crystal lattice, and also has most of the exchange positions occupied by calcium ions. It is a swelling-type clay, but not to as great an extent as a sodium montmorillonite. The other clay minerals, kaolinite and illite, are nonexpanding clays and also will disperse in water, as will the beidellite. All of these clay minerals will contribute to the opacity of a suspension of the sample in water.

APPENDIX C

Some Engineering Considerations
by P. F. Enger

Limnophotometer readings were plotted to determine percent of light reduction, at various depths, from intensity of light at the water surface. Plots of data, Figures 1 and 2, indicate percent reduction to be a log normal function. Data plotted well with practically no deviation (skewness) at the tails; however, some deviation from the log normal function occurred in central terms. The tails, which are of greatest interest, can be easily and fully described by substituting for the depth below water surface (y), a function of the log of the depth y_ϕ.

$$y_\phi = \log_2 y$$

As there is no skewness of the tails, the normal or Gaussian equation resulting can be written in the form:

$$\Phi(y_\phi) = \frac{100}{\sigma_\phi \sqrt{2\pi}} \int_{-\infty}^{y_\phi} e^{-\frac{1}{2}\left(\frac{y_\phi - M_\phi}{\sigma_\phi}\right)^2} dy_\phi$$

where:

(y_ϕ) = percent reduction in light for depth y_ϕ below surface

M_ϕ = $\log_2$ of a mean depth where 50 percent light reduction would occur, if normal equation were to follow tails condition

6_ϕ = standard deviation in terms of $\log_2$ of y_ϕ, 100- is used as a constant to change light reduction to a percentage

For the substitution log to the base 2 ($\log_2$) was selected. This results in easy plotting as $\log_2 1 = 0$, $\log_2 2 = 1$, $\log_2 4 = 2$, $\log_2 8 = 3$, etc.

The M_ϕ and O_ϕ values for the curves determined with the opal glass are shown in Figures 1 and 2.

To determine percent light reduction due to sediment, the percent light reduction for a given depth in the control drum was subtracted from the percent light reduction at the same depth in drums containing sediment. Plots of the results are shown in Figures 3 and 4. The figures show light reduction for total visible portions of the spectrum.

Studying the figures shows that for depths of less than 1 foot (30.5 cm) below the water surface, percent light reduction due to various concentrations of suspended sediment varies considerably. However, at depths of more than 1 foot below the water surface, all sediment concentrations approach the same percentage light reduction. One exception is the low concentration of 50-ppm Angostura Reservoir sediment. The 50-ppm curves appear to differ from the curve families by from 5 to 10 percent. No light reduction readings were obtained at concentrations of less than 1,250 ppm for the sodium-base montmorillonite bentonite.

These graphs indicate that at depths of water greater than 1 foot, a 250-ppm concentration of a given suspended sediment would be nearly as effective in reducing radiant energy as a 5,000-ppm concentration of suspended sediment, and that a 50-ppm concentration would be only slightly less effective. This conclusion is, of course, restricted to the range of light waves measured, and the accuracy of the instrument.

To establish relations of percent reduction by weight of weed growth versus concentration of suspended sediment, least square lines were fitted to the data of Table 2. Two logarithmic least square lines were fitted to Angostura sediment data, and one to the limited range of data available for the commercial bentonite. For Angostura data, one line was generally fitted to data of less than 1,000-ppm concentration, and another line for data greater than 1,000 ppm. The resulting curves are shown in Figure 5. Though the number of data available were limited, correlation coefficients were obtained. Correlation coefficients were generally high for data below 1,000 ppm. Scatter of data at concentrations greater than 1,000 ppm, and a flattening of the curve resulted in lower correlation coefficients. Equations resulting from fitting least square curves, with their limits and correlation coefficients, follow:

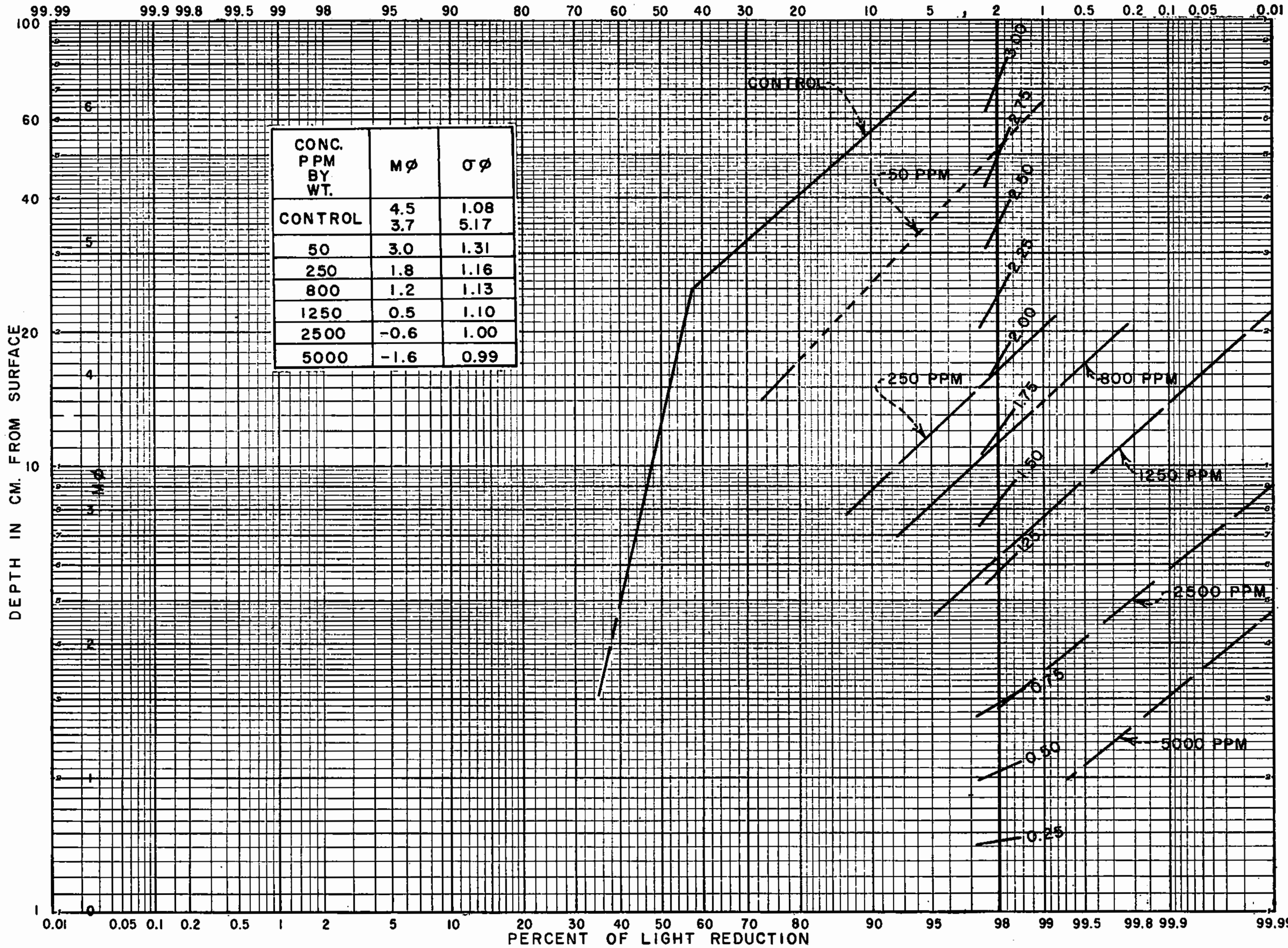
ANGOSTURA SEDIMENT

Plant	Equation	Limits	Correlation coefficient
P. pectinatus	R = -42.3 + 46.4 Log C	50<C<900	0.99
P. pectinatus	R = 84.6 + 3.52 Log C	900<C<5,000	0.46
P. nodosus	R = -50.9 + 45.0 Log C	50<C<850	0.99
P. nodosus	R = 49.5 + 10.7 Log C	850<C<5,000	0.32
E. canadensis	R = -19.5 + 33.4 Log C	50<C<780	0.99
E. canadensis	R = 68.8 + 2.74 Log C	780<C<5,000	0.77
Average of the	R = -37.5 + 41.5 Log C	50<C<850	0.99
three plants	R = 67.3 + 5.76 Log C	850<C<5,000	0.49
	SODIUM-BASE BENTONITE		
Average condition	R = -94.8 + 50.8 Log C	1,250 C 5,000	0.91

Where: R = percent reduction by weight of growth.
C = concentration of suspended sediment in parts per million by weight.

The experiments described in the report were conducted in drums where the mean velocity was directed toward the water surface and there was no resulting average horizontal velocity. In flowing canals or laterals the opposite is true, or, the mean velocity is in the direction of the canal or lateral, and there is no resulting average upward velocity. As plants are by no means rigid, any resulting horizontal velocity will tend to deflect them. (In these tests, resulting upward velocities did not tend to create a horizontal deflection of the plant.) In the field, any lateral velocity would force plants to deflect at various angles, depending on the velocity of the water and the condition of the plant. This would require the plant to produce longer stems than those produced by plants in these tests before its tip reached a comparable light intensity. Figure 6 is a graph of the additional elongation required versus the angle of deflection. Assuming a channel 3 feet deep and that light for aiding plant growth is not available at depths of greater than 1 foot below the water surface, the figure indicates that if the velocity were such that a deflection between plant tip and root of 60° resulted, it would be necessary for the plant to become twice as long to reach the same level of light intensity as those tested. However, velocity fluctuations of the flowing water may result in fluctuations of the plant which would aid in reducing the effective elongation necessary to reach the light source. There is the possibility that resulting deflections plus fluctuations may contribute such small corrections that they can be neglected. It is also possible that the plants may be forced to such lengths as to actually create more obstruction to the flow.

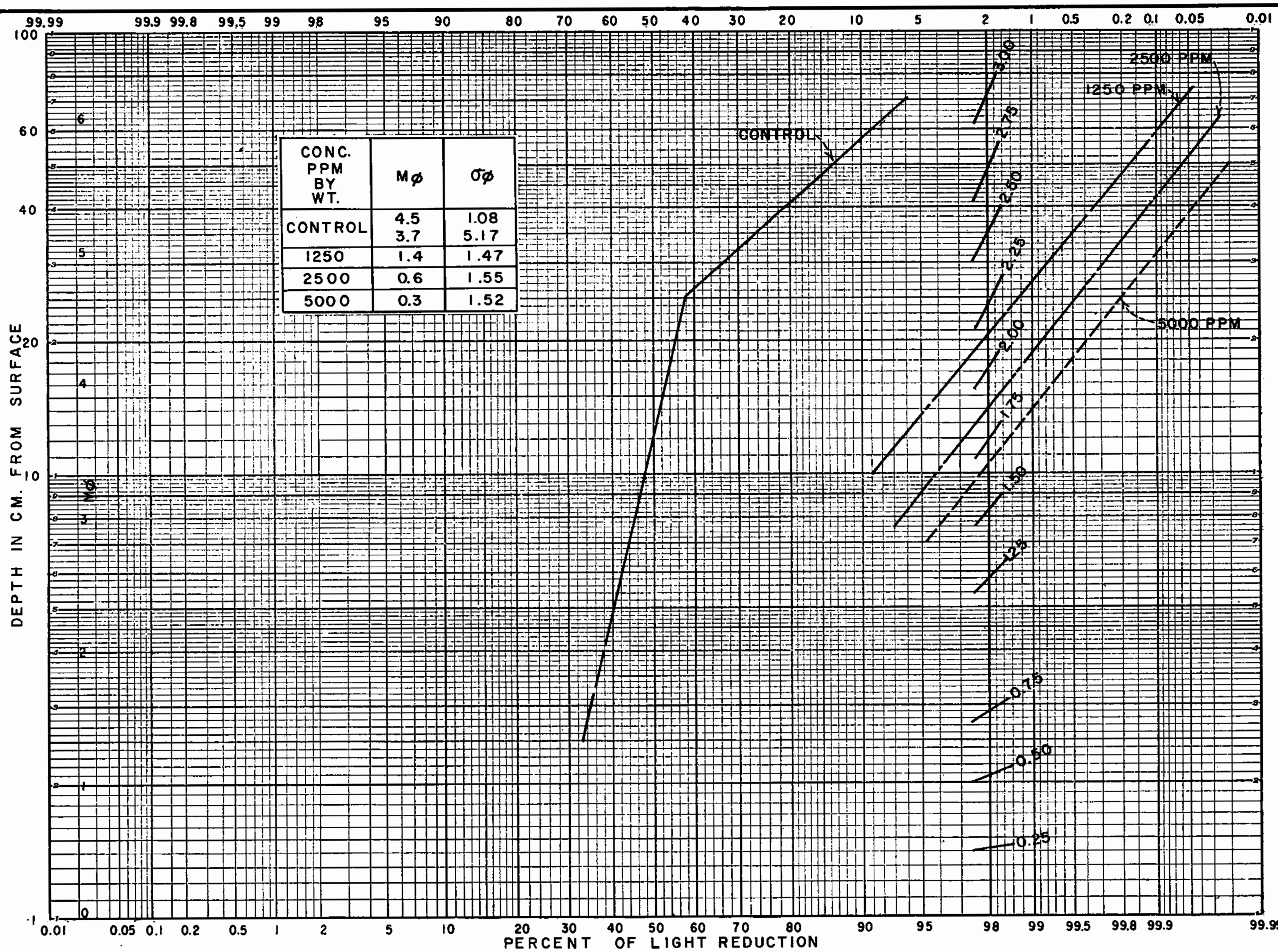
From preceding discussions, it becomes obvious that reduction in growth of a given plant in a flowing channel cannot be related simply to the concentration of suspended sediment, but must be a function of: (1) concentration of suspended sediment, (2) type of suspended sediment, (3) velocity of water in the channel, and (4) depth of water in the channel. Also, plant response will depend on type of plant and other biological factors within the plant and soil. These discussions show the equations given should be considered as applying only to the test conditions used in this study, and that additional studies would be necessary to evaluate other effects.



CONC. PPM BY WT.	Mø	σø
CONTROL	4.5 3.7	1.08 5.17
50	3.0	1.31
250	1.8	1.16
800	1.2	1.13
1250	0.5	1.10
2500	-0.6	1.00
5000	-1.6	0.99

PERCENT LIGHT REDUCTION RECORDED WITH OPAL GLASS IN PLACE IN WATER CONTAINING ANGOSTURA RESERVOIR SEDIMENT

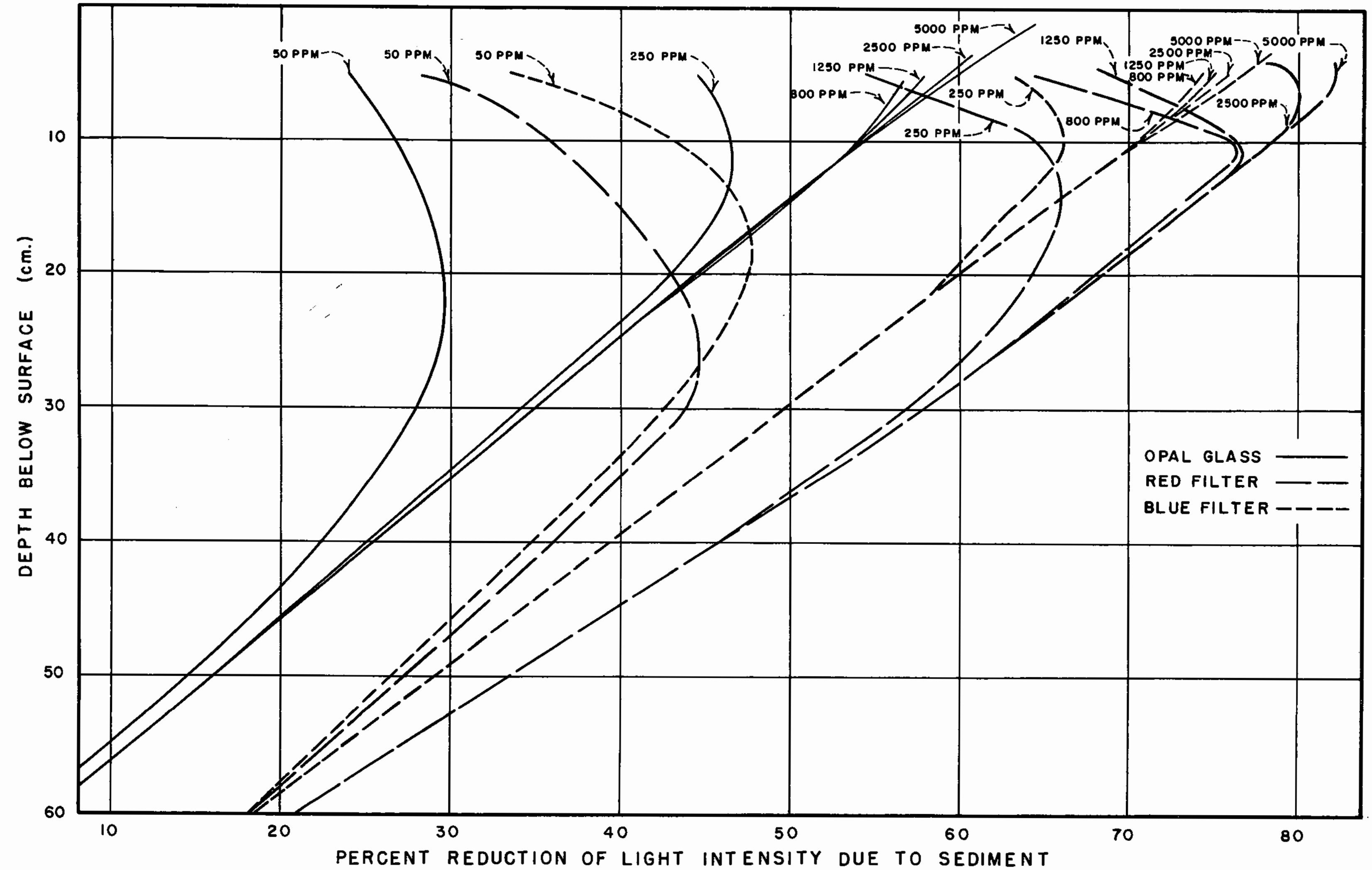
FIGURE I
APPENDIX C- REPORT GEN. 27



CONC. PPM BY WT.	Mφ	σφ
CONTROL	4.5 3.7	1.08 5.17
1250	1.4	1.47
2500	0.6	1.55
5000	0.3	1.52

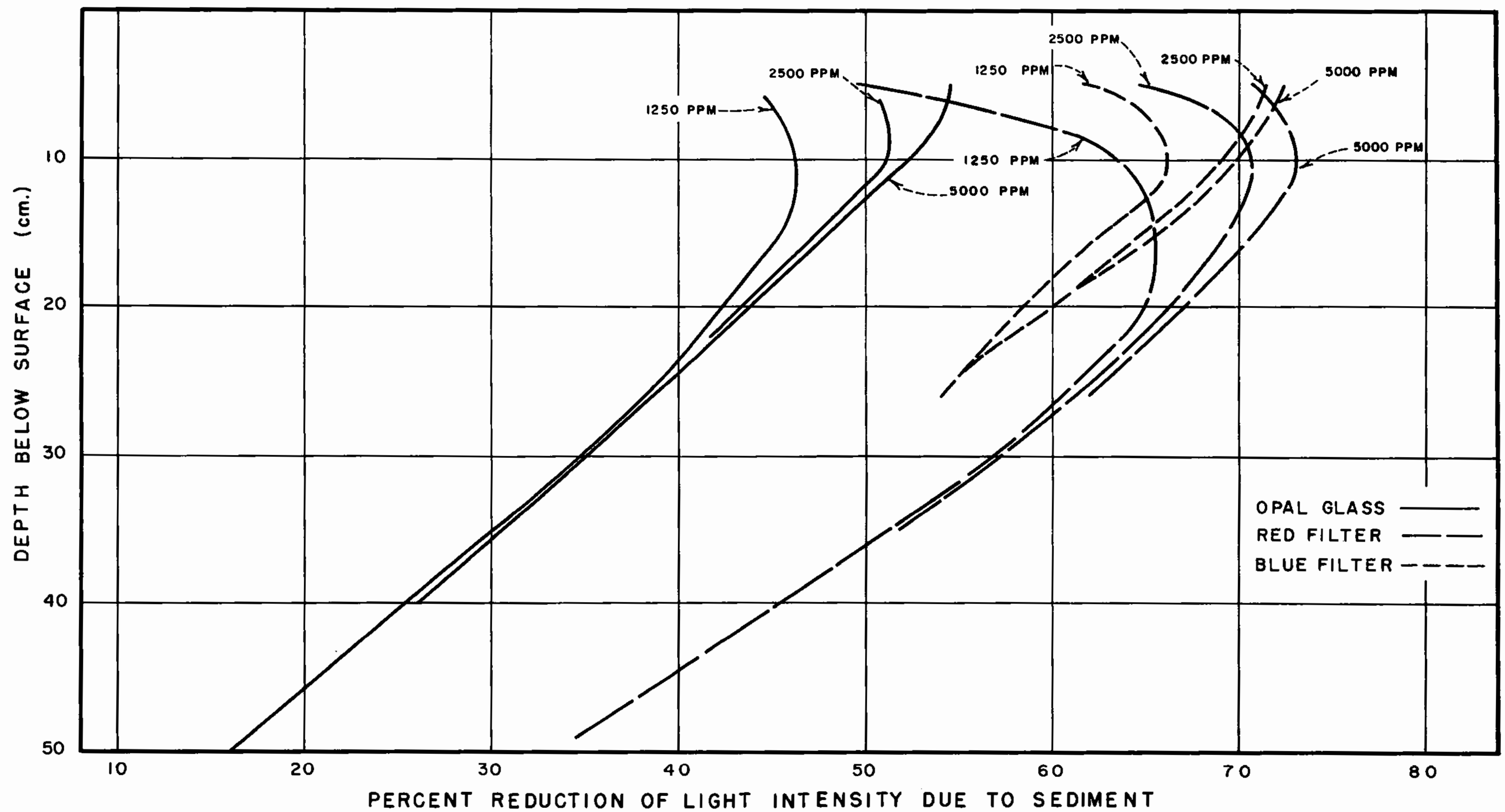
PERCENT LIGHT REDUCTION RECORDED WITH OPAL GLASS IN PLACE IN WATER CONTAINING SODIUM-BASE MONTMORILLONITE BENTONITE

FIGURE 2
APPENDIX C- REPORT GEN.27



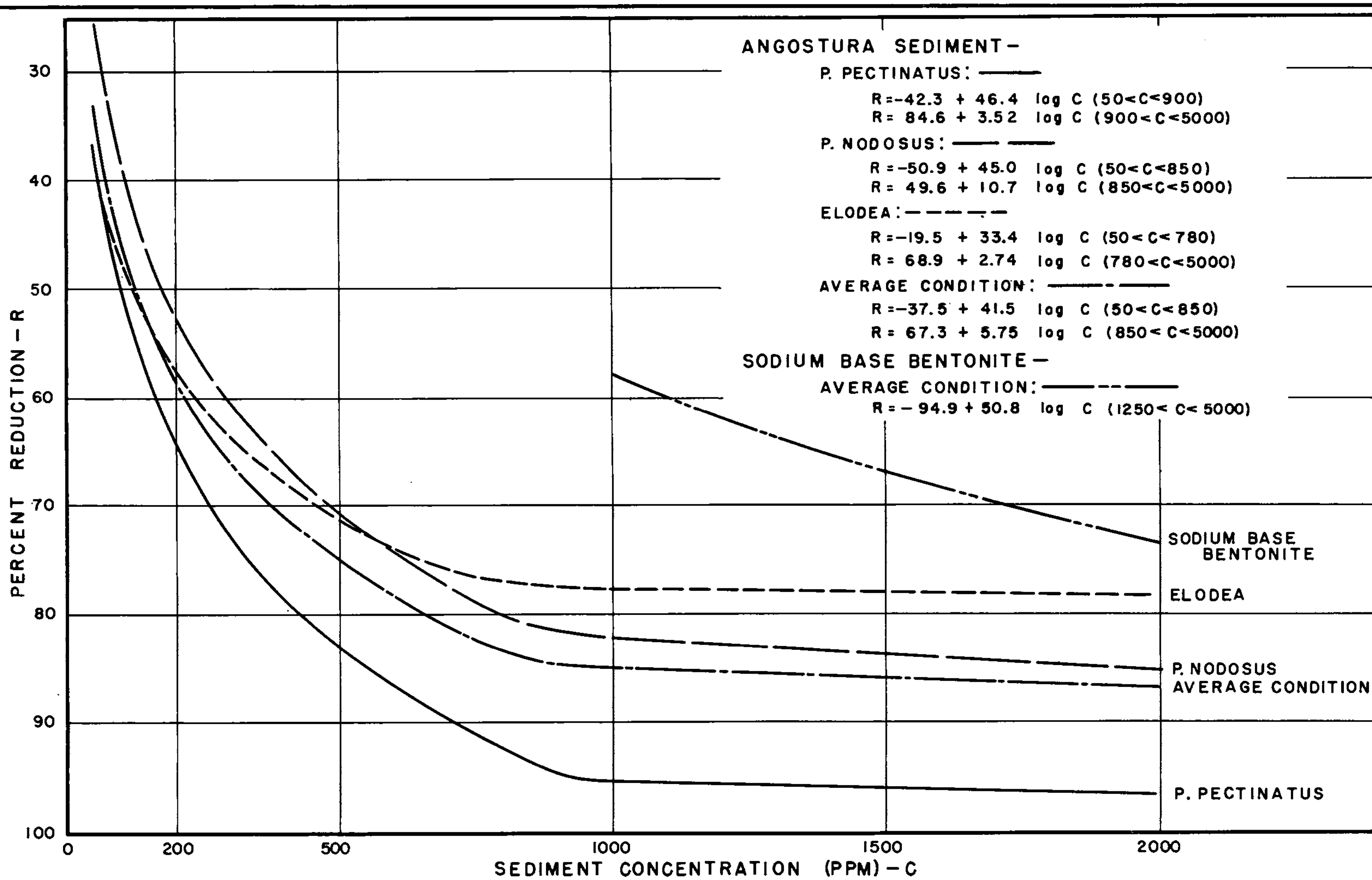
PERCENT REDUCTION OF LIGHT INTENSITY DUE TO ANGOSTURA RESERVOIR SEDIMENT CONCENTRATIONS AT VARIOUS DEPTHS BELOW THE WATER SURFACE

FIGURE 3
APPENDIX C-REPORT GEN. 27



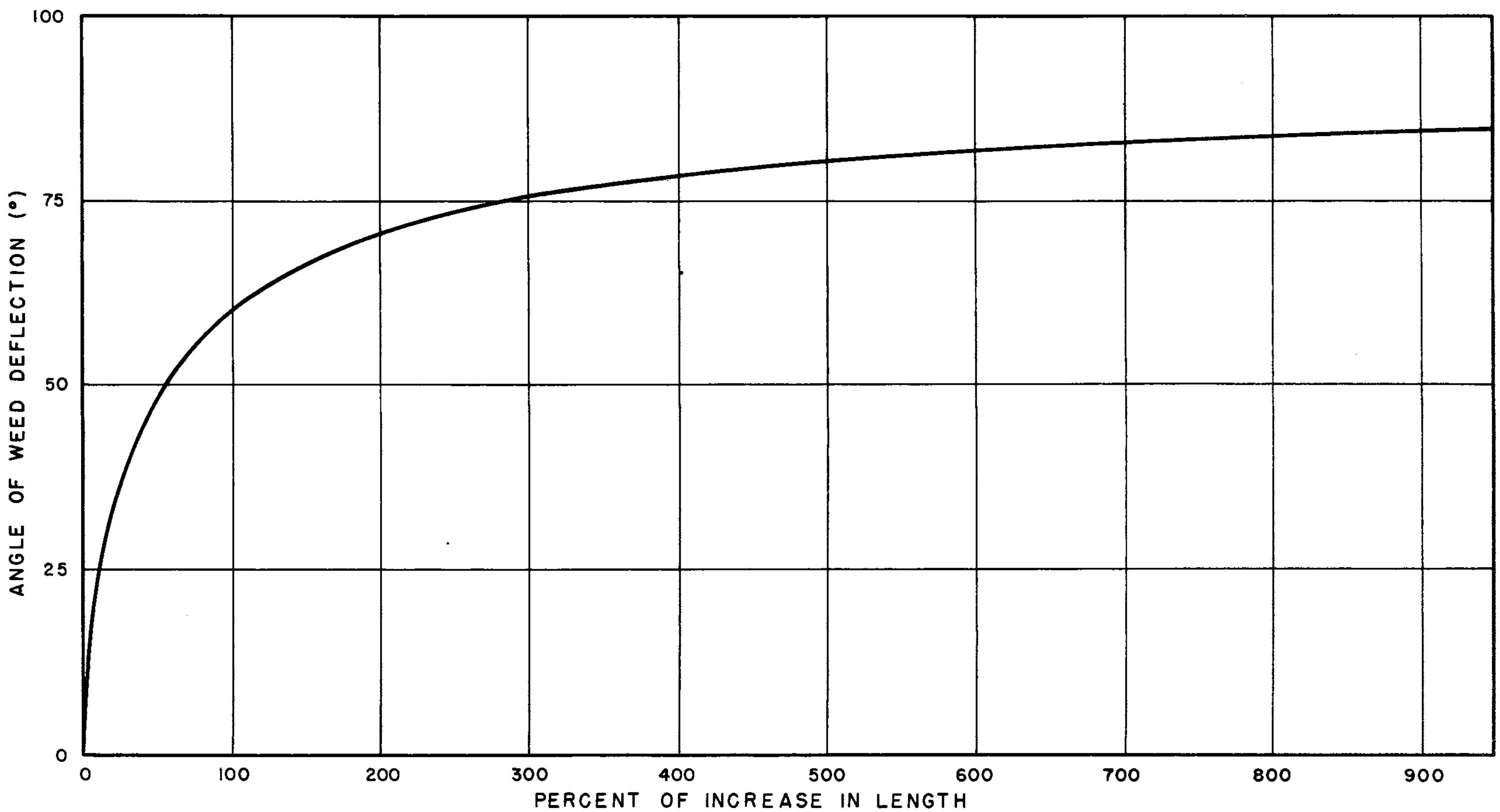
PERCENT REDUCTION OF LIGHT INTENSITY DUE TO SODIUM-BASE MONTMORILLONITE BENTONITE SEDIMENT CONCENTRATIONS AT VARIOUS DEPTHS BELOW THE WATER SURFACE

FIGURE 4
APPENDIX C-REPORT GEN. 27



PERCENT REDUCTION BY WEIGHT OF DIFFERENT PLANT MATERIALS AS A FUNCTION OF THE SEDIMENT CONCENTRATION

FIGURE 5
APPENDIX C-REPORT GEN. 27



PERCENT INCREASE IN STEM LENGTH NECESSARY FOR PLANT TO
REACH A COMPARABLE LIGHT INTENSITY IF PLANT IS DEFLECTED BY VELOCITY

FIGURE 6
APPENDIX C-REPORT GEN. 27