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STREAM RECLAMATION TECHNIQUES

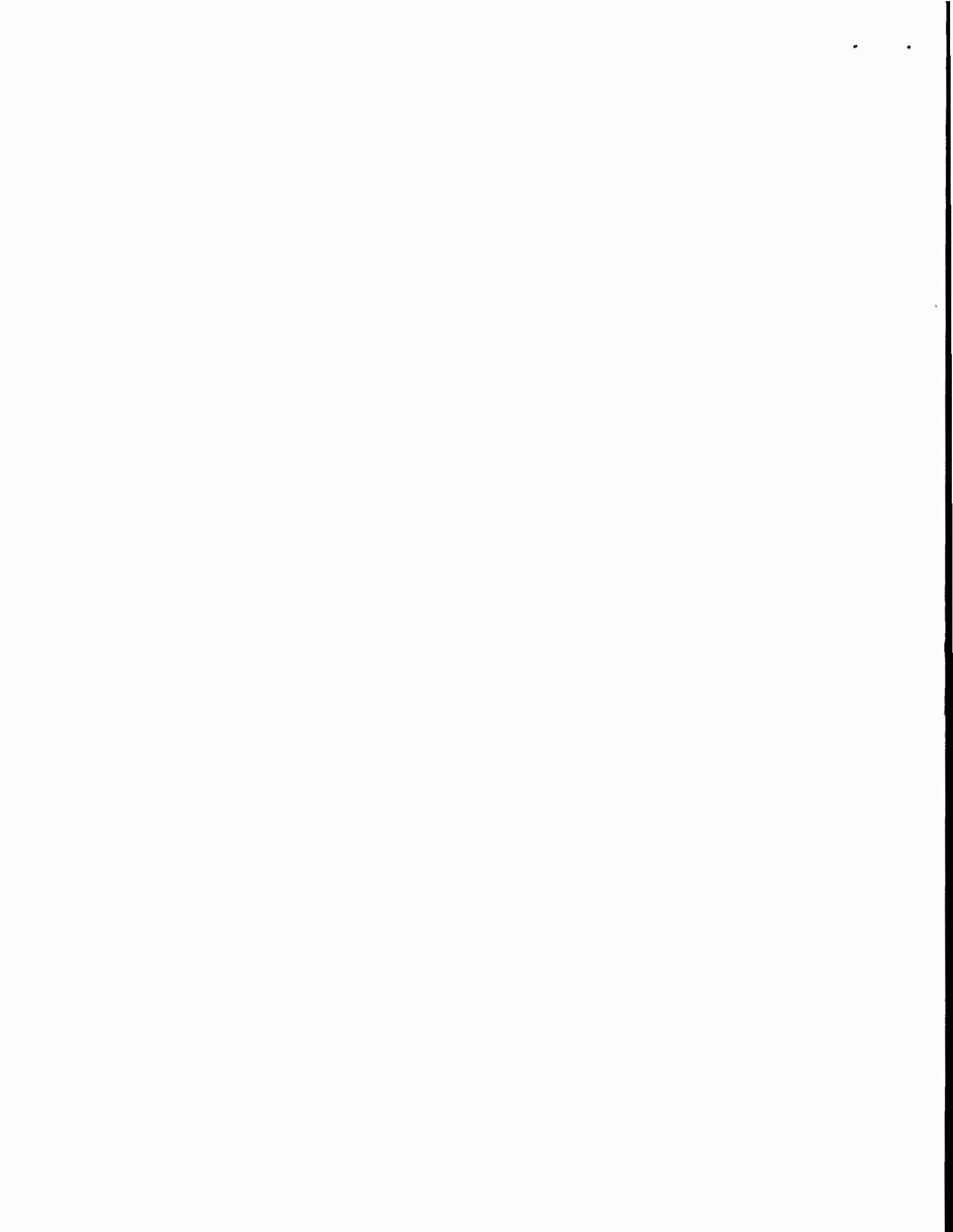
by

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INTRODUCTION

Reclamation of streams can be an extremely effective management technique. The effectiveness of this management tool is, however, closely related to the methodology employed. In this report, I have collected pertinent information from a variety of sources and in the light of our own experiences and needs, present a comprehensive, step by step outline for successful stream reclamation.

Lennon and Parker (1959) observed, "There are important problems involved in the reclamation of running water. A lethal concentration of toxicant must be maintained over miles of stream despite factors of stretchout and dilution. The fish at any given point in a stream must be exposed to the toxicant for an effective length of time in order to obtain a kill. These problems are complicated by the variable rates of stream discharge and velocity, by the temperature of the water and by the greatly divergent susceptibilities of various species of fish to a toxicant at a given concentration and periods of exposure. Consequently, the dimensions of a bolt of toxicant (chemical prism) moving downstream have to be carefully prescribed."

Early attempts (Lennon and Parker; Fernholz and Frankenberger 1966; Fernholz and Slifer 1967) at describing a prism of toxicant involved measuring downstream decreases in stream resistivity readings caused by short introductions of salt solutions as proportional indicators of dilution.

Laboratory test (author - unpublished) proves that salt content plotted against resistivity does not yield a directly proportional relationship (Fig. 1) and that substantial errors can be made by basing calculations of toxicant requirements on this assumption. A new approach utilizing the linear relationship of salt content against conductivity is now available for prism analysis.

Further understanding of the nature of short chemical prisms in streams requires modification of old, inaccurate techniques while increased knowledge of various fish toxicants provides new concepts and new tools that project managers should incorporate into their stream reclamation programs.

The size of the stream that can be treated utilizing the salt tracer technique is limited in practice by the large quantities of salt required for large stream flows and by the length of time required to collect the necessary data on exceptionally long or very sluggish stream systems.

SALT AND CONDUCTIVITY RELATIONSHIPS

McCoy and Ratledge (1967) determined from experiments on three different North Carolina trout streams that the regression of specific conductance (y) on salt content (x) at 65°F. was almost perfect with a regression coefficient of 1.85.

Recent laboratory test at Black River Falls, Wisconsin (author), on a sample of soft, brown-stained water obtained locally confirmed a linear regression of specific conductance (y) on salt content (x) at 77°F. (Fig. 2). The regression coefficient was calculated at 2.19, yielding a prediction equation of

$$y = 18.09 + 2.19x$$

The regression of y on x was nearly perfect as evidenced by a correlation (R) of 0.999. The t value was calculated at 366.9.

The 99.95 percent confidence limits of the slope of the regression line are 2.19 ± 0.0025 .

Subsequent reevaluation of the N. Carolina data, this time converting conductivity values to our standard of 77°F., yielded a regression coefficient of 2.14 indicating a slope that is highly compatible with our laboratory test.

These data suggest that the value of the regression coefficient and hence the slope of the line it describes may be temperature dependent--therefore accurate correction of all resistance readings to the standard of 77°F. (Table 1) before conversion to conductance is very important.

The inverse-prediction equation for salt-resistivity data is . . .

$$x = (y_o - a_o) / b_1$$

where

x = ppm. salt present

y_o = measured resistance as the salt prism passes, corrected to 77°F. (Table 1) and converted to conductance--

$$\text{Conductivity} = \frac{1,000,000}{R @ 77^{\circ}\text{F.}}$$

a_o = Observed natural resistance corrected to 77°F. and converted to conductance--

$$C = \frac{1,000,000}{R @ 77^{\circ}\text{F.}}$$

b₁ = 2.19 (regression coefficient)

Conversion of data to the 77°F. standard is quite simple. If a conductivity meter is available, direct readings may be taken at existing stream temperatures and converted to 77°F. using the appropriate column in Table 1. This eliminates the need to convert resistance to specific conductivity.

A resistivity meter can also be used to collect data for the regression equation if the values are properly corrected for temperature and converted to conductance.

DETERMINING STATION LOCATIONS

Before conducting test on the stream itself, it is necessary to decide on station locations--points where additional toxicant will be added to keep the concentration up to a lethal level.

In normal stream situations, dilution will approximate 50 percent per mile although wide variations can be expected in some situations.

Access permitting, it is most convenient to select stations approximately one mile apart. This frequently avoids the necessity of having to introduce massive doses of toxicant at one station in order to maintain a lethal concentration at the next downstream station. Bridge crossings make excellent

station locations as they are readily accessible and are easily identified.

Once stations have been selected and marked on the map, accurate flow readings are taken at each station. A station on the main stream must always be established immediately above the confluence of a major tributary. It is important that this station be above the mouth of the tributary.

Similarly, when locating stations on major tributaries, the lowermost station should be on the tributary near its junction with the main stream. The lowermost stations on these major tributaries are used only to monitor the strength of the salt prism before it enters the main stream.

All other stations on the tributaries and main stream, excepting at the terminus of the project, will be used to introduce and monitor salt as well as introduce toxicant.

DEVELOPING A TEST PATTERN

It is desirable that a minimum of 50 ppm. salt be introduced to create a salt prism of significant magnitude for downstream measurement.

Philip Gilderhus (U. S. Fish Control Laboratory, La Crosse, Wis. - personal communication) has demonstrated that it is also necessary to introduce the salt concentration for a relatively long period of time in order to make the peak reading of the salt prism at any downstream location dependent upon increase in stream flow and independent of the length of the injection period (Fig. 3). Preliminary tests by Gilderhus on a one-mile stretch of stream, having a 70 to 30 percent pool riffle ratio, indicated that a two-hour injection of tracer was necessary to give a true peak with a 30-minute plateau. Shorter periods of tracer injection resulted in sharp peaks which were obviously dependent upon the length of time the tracer was introduced.

In streams having a very large percent of their lengths in large, deep pools, longer periods of tracer injection may be required to permit saturation of the stored water. In streams with rapid flows or fewer pools, a shorter tracer injection period may be sufficient.

Salt is most effectively introduced into a stream by dissolving a measured quantity in a container with a faucet-type valve.

McCoy and Ratledge note that pounds salt per hour = (cfs.)(0.225) (ppm. desired). They recommend that the quantity of salt required per hour of application be divided and introduced into the stream in quarter portions over 15-minute periods to eliminate the possibility of a one-hour portion of salt being accidentally released in a much shorter period of time.

McCoy and Ratledge express preference for starting a salt prism at Station #1 and following it through to the end of the project, injecting additional salt at each downstream station just as will be done later with the fish toxicant. They report an average prism travel time of seven hours per mile in four reclaimed North Carolina trout streams.

This method involves identifying the peak of the passing salt prism at Station 2 at the earliest possible moment. Then while continuing to monitor the arriving prism, additional quantities of salt are added a few feet downstream to reinforce the prism as it passes. Crews are worked day and night to follow and reinforce the salt prism.

We have obtained satisfactory results by running salt test on each pair of stations independently of each other. We have also found it desirable to work upstream, i.e., to complete the lower stations before doing the upstream stations to prevent lingering salt concentrations from interfering with the next test.

This latter approach provides ample opportunity to observe the entire salt prism and to design a toxicant prism without attempting to follow the salt prism throughout the night. This approach also eliminates the potential error due to the different rates of loss of chemical concentration that are time dependent. McCoy and Ratledge report that their studies indicated no significant difference between the concentration of chemicals (salt and rotenone) when the distance between stations did not exceed two miles but

postulate that, over a larger period of time, the toxicity of rotenone will be reduced by aeration, light, dilution, longitudinal mixing, and natural decomposition at a faster rate than salt is reduced by dilution and its affinity for other stream chemicals.

PROCEDURE FOR SALT - CONDUCTIVITY TEST

The procedure and calculations for a hypothetical stream with three stations above the detoxification point (called Sta. 4) would be as follows assuming that 50 ppm. salt were introduced for a 2-hour period to measure the extent of stream dilution.

Beginning the test at the lowermost station for the stretch of stream between Station #3 and Station #4:

At Station #3

1. Determine the natural specific conductance of the stream, correct to 77° F. (Table 1) - example 18.9 @ 77° F.
2. Determine (meter) stream flow (3 cfs.).
3. Calculate pounds of salt required per hour to give desired concentration = (cfs.)(0.225)(ppm. desired) = (3)(0.225)(50 ppm.) = 33.75 pounds of salt per hour or 67.5 pounds of salt in two hours.
4. Divide hourly salt requirements into quarter portions (8.44 lbs.) and introduce each quarter portion over successive 15-minute intervals until all the salt has been applied.

CAREFULLY NOTE THE TIME OF INITIAL INTRODUCTION.

If, by miscalculation, one-quarter portion of salt is released in only 10 minutes, wait until the full 15 minutes has elapsed before proceeding with the next portion. The effects of minor errors in release will level themselves off as the prism passes through pools.

5. As an optional check for the actual ppm. salt introduced, wait until you have been introducing salt for about one hour, then move 100-300 feet downstream and determine the specific conductance at 77° F. and

solve the inverse prediction equation as follows for x.

$$x = (y_0 - a_0) / b_1$$

where x = ppm. salt present

y_0 = observed salt influenced specific conductance @ 77° F.

a_0 = natural specific conductance @ 77° F.

b_1 = 2.19 (a constant)

Then, when all the salt has been introduced, proceed to the next downstream station (#4).

At Station #4

1. Determine natural conductivity of water, correct to 77° F. (example 19.2).

Note: Slight increases in natural resistivity are frequently noted at lower points on the stream.

2. Determine and record conductivity values in the stream at 5- to 10-minute intervals as the salt prism passes. CAREFULLY NOTE THE EXACT TIME OF EACH READING. The observed rise, leveling off and subsequent decline in specific conductivity will describe the passing salt prism.

3. For the purpose of later toxicant calculations, it is necessary to observe the series of high and nearly equal conductivity values (plateau), select a representative average and convert this value to 77° F.

For our example, we shall use a conductivity value of 61.3 at 77° F. to describe the plateau.

Using only data collected at this station, the inverse prediction equation

$$x = (y_0 - a_0) / b_1$$

is solved as outlined ~~for~~ Station #3

$$x = (61.3 - 19.2) / 2.19 = \frac{42.1}{2.19}$$

x = 19.22 ppm. salt remaining in the peak of the prism.

Recalling that 50 ppm. were introduced upstream, calculate that 61.6% of the peak concentration was lost or the 38.4% remains.

Moving upstream to test the section of stream between Station #2 and Station #3, the same procedure is followed as has been previously outlined for the stream sector between Station #3 and #4. In a similar fashion, all parts of the stream are investigated, including all major tributaries and selected representative minor tributaries.

TOXICANT SELECTION AND APPLICATION RATES

Lennon and Parker (1959) investigated the concentrations of a 5 percent rotenone compound and the length of exposure time required to kill 24 species of fish including hogsucker, carp, river chub, catfish, and bullhead.

One conclusion from this study was that 23 of the 24 species tested could be killed in a stream if this piscicide were maintained at 1 ppm. for six hours at a water temperature of 60°F. or higher. Goldfish were killed in only one of the six tests.

Gilderhus reported the results of preliminary efficacy test of rotenone in a simulated stream situation using water with a pH of 8 and a total hardness of 300 ppm. (personal communication).

He found that at 53°F., 20 percent of the test carp could survive 15 hours exposure to 5 ppm. Noxfish, even though all fish ceased to show visible external signs of life after only four hours exposure.

Nine hours exposure to 5 ppm. Noxfish were required to kill 100 percent of the tested common suckers.

These preliminary and limited tests should serve to alert interested personnel to the potential limitations of rotenone in cold water situations common to many of our trout streams.

Antimycin A, an antifungal antibiotic, ~~has~~ recently been receiving careful attention as a fish toxicant. Walker and Lennon (1964) observed that it was lethal to certain target fishes in low concentrations and on short exposure;

that it produced effective kills in cool or warm water and that it rapidly degrades in water leaving no harmful residue. They report that plankton, aquatic plants, and bottom fauna were not harmed by piscicidal concentrations.

Toxicant concentrations necessary to accomplish complete eradication are dependent upon pH, water temperature, and species of fish present.

Further test by Gilderhus reveals that under simulated stream conditions with water of pH 8, total hardness of 300 ppm. and at 53°F., a 100 percent kill of carp was obtained after only six hours exposure to 10 ppb. antimycin while suckers need be exposed only four hours at this concentration to insure a complete kill. Antimycin offers further advantages in streams of all temperatures in that it does not cause apparent discomfort to the fish being treated and hence no efforts by the fish to escape to cleaner or fresher water has been observed.

Antimycin is notably ineffective against channel catfish, black bullhead, and yellow bullhead at all water temperatures and goldfish at cooler water temperatures within reasonable application rates. For control of most other problem species commonly encountered in Wisconsin trout streams, maintenance of a minimum concentration of 10 ppb. Fintrol concentrate for a period of not less than 9-10 hours can be expected to produce a complete kill.

It is readily foreseeable that under certain conditions, it may be desirable to treat portions of the system with rotenone and other portions with antimycin. Water temperatures permitting, time to death following exposure to the toxicant may be an important factor and rotenone kills with greater speed. In warm water tributaries or in the warmer, lower stretches of a stream, the presence of undesirable populations of members of the catfish family may make treatment with rotenone desirable. In projects involving large quantities of water, comparative cost of the two toxicants may dictate the use of rotenone where stream temperatures are favorable.

Howland (1969), from bioassays using Antimycin A, Chemfish and the two piscicides in combination, determined that the two chemicals used together appear to have a slight additive effect, but that more importantly, they do not nullify each other.

COST CONSIDERATIONS IN TOXICANT SELECTION

It might be noted that in the following examples, 547 ounces of rotenone (4.27 gal.) would be required at a summer 1969 cost of \$3.20 per gallon.

For the same hypothetical stream, 2,133 ml. of Fintrol concentrate (4.44 units) would be required at a cost of \$25.00 per unit.

Comparison of toxicant cost for the project would then be \$13.67 for rotenone vs. \$111.00 for antimycin. Thirty-three dollars of this higher antimycin cost is due to the longer exposure period required for antimycin resulting in an additional four hours of toxicant introduction at the minimum rate.

Since 10 hours introduction antimycin is currently recommended as opposed to six for rotenone, a higher total manpower expenditure would be expected for antimycin projects if the toxicant metering apparatus required very much attention.

NATURE OF CHEMICAL PRISMS

Observations of salt prisms in flowing streams demonstrate that, stored water in the stream tends to depress chemical concentrations in the forward and trailing edge of a moving prism. This erosion forms a prism with a front sloping from a zero concentration up to the plateau value which is probably determined primarily by the increase in stream flow (Gilderhus 1969). The concentration of chemical observed in the plateau eventually slopes back to zero as the prism passes (Fig. 3).

Depending upon the quantity of stored water in the stream section, the length of the prism's plateau (the actual length of exposure of fish to the desired minimum concentration of chemical) is continually shortened as the prism continues to progress downstream and both ends continue to erode.

Salt-conductivity test for any pair of stations adequately describes both this erosion, due to stored water, and the depression of the plateau value.

While relatively simple calculations will serve to determine the amount of toxicant needed to reinforce that portion of the prism contained under the plateau, the variable nature of the sloping forward edge does not readily lend itself to practical mathematical analysis and even if it did, any subsequent chemical introduction would require continual in-the-field adjustment of toxicant input from a high to a lower rate as the plateau approached.

The simplest solution to this problem appears to lie in introducing an excess of toxicant in the forward edge of the moving prism so that any predicted erosion of the prism on its way to the next station will not reduce concentration values in the first hour of the prism below that considered to be the minimum lethal value for the toxicant used.

Gilderhus observed in a test stream consisting of 70 percent pools that while a dye injection of two hours was necessary to provide a prism with a plateau of sufficient length to be of useable value, a one-hour injection would provide a prism with plateau that, while extremely short, provided a peak value consistent with the value observed in the two-hour prism. It appears likely therefore, that in stream situations of this type or in streams with fewer pools and less stored water, it would be relatively easy to calculate the quantity of toxicant necessary to maintain a safe chemical excess in the forward edge of the entire prism.

Once the forward edge of the toxicant prism is adequately protected, the shortest possible constant introduction rate of further chemical can be easily calculated.

In West Central Wisconsin trout streams, Fernholz and Slifer observed that effective kills with rotenone could be obtained by no less than maintaining a peak concentration of excess toxicant in the forward portion of the prism that was equal to five times the desired minimum concentration for the remaining portion of the prism.

TOXICANT CALCULATIONS

Discussion: If, from salt-conductivity test, a 30 percent decline in salt concentration is observed between Station #1 and Station #2, it is then expected that any toxicant concentration will be diminished by 30 percent on its way to Station #2.

Therefore, if 5 ppm. chemical concentration is desired at Station #2, but only 70 percent of any concentration introduced at Station #1 will remain, it is calculated ($.70x = 5$ ppm.) that 7.14 ppm. concentration would be needed at Station #1. This concentration of chemical, based on the flow of Station #1, is necessary to get a peak of 5 ppm. to Station #2. It is noted that 7.14 ppm. in a flow of 5 cfs. = $(7.14)(5)(3.456) = 123.4$ ounces of rotenone/hr. required at Station #1.

However, since toxicant concentration in the stream is directly dependent on the quantity of chemical added under one particular set of circumstances^{1/}, it is logical to deal directly in terms of chemical quantities. It is also practical as it saves several steps in toxicant calculations.

The question in terms of chemical quantities is $.70x = 86.4$ ounces/hour where 86.4 is the calculated amount of chemical amount required at Station #1 to give 5 ppm. at Station #1 and x is the unknown quantity of rotenone needed to give a 5 ppm. peak concentration at Station #2. Then $x = 123.43$ ounces rotenone/hour. Similar calculations for each pair of stations on the stream will provide basic data needed to derive final toxicant introduction rates after appropriate consideration is made for quantities of useable toxicant arriving from upstream stations (see appendix for examples).

^{1/} This is true only at the upper station of any pair during the time of actual introduction of the chemical. At any point downstream, concentration will be dependent upon length of injection, dilution due to increased stream flow, longitudinal mixing, and some other minor factors.

TIMING THE PROJECT

On a spare project map which shows the location of each station, record the time information collected from salt-conductivity test. For Station #1, record the time that the salt prism was begun. For Station #2, record the time that the center of the plateau of the passing prism arrived. Calculate the hours and minutes of time elapsed, subtract 30 minutes, and record this value on the map between Station #1 and #2. Subtracting 30 minutes will serve to center the one hour dose of reinforcing toxicant around the peak of the prism passing Station #2.

Similar calculations must be completed for every pair of stations on which salt-conductivity tests were run, i.e., 2-3, 3-4, 4-5, and 5-6 in our example. Values for tested tributaries should be calculated also.

Timing the project becomes a simple matter of choosing a time that you wish the toxicant to reach the detoxification point. Then back calculate upstream, station by station to determine the time that each station on the main stream and each tributary must go into operation.

INTRODUCING TOXICANT (Equipment)

Toxicant introduction must begin at each station at the time indicated by your time studies (previous section). The one-hour injection of chemical at the rate calculated in Column E, Table 2, is followed immediately by introduction of a quantity of toxicant equal to $1/5$ the Column E value per hour for an additional 5 hours or 9 hours for rotenone or antimycin respectively.

The simplest type of device that may be used for chemical introduction consists of a 5-gallon pail in which a spigot has been installed. This apparatus has proven generally unsatisfactory for toxicant introduction because as the fluid level in the pail drops, the rate of flow from the spigot decreases and it is therefore necessary to have an attendant on duty at the station full time to continually readjust the flow rate.

In an attempt to correct this disadvantage, an automobile carburetor was connected to a line leading from the pail. While the flow rate tended to

remain constant throughout the period of toxicant introduction, the carburetor system proved unsatisfactory because it was easily plugged by small amounts of debris or by the gummy mixture of rotenone and water itself. As a result, frequent checks and dismantling of the system for cleaning were required during the project.

The only completely satisfactory metering device we have found was described by Anderson (1962). It consists of a 72 amp. hour wet cell, 12-volt battery, an electric fuel pump and the necessary tubes and fittings required to permit accurate adjustments of delivery rates.

My tests of this unit have shown that completely stable delivery rates of various mixtures of water and rotenone over 12-hour periods can be expected.

Extensive field use of 9 of these units has demonstrated their complete reliability with rotenone and liquid antimycin.

The day before the project begins, the fish toxicant is measured. We have found that it is most practical to mix the needed quantity of toxicant with sufficient water to make 5 gallons.

For each station, two containers are needed. In one container, add water to the quantity of toxicant indicated in Column E. For rotenone, repeat the procedure in the second container. For antimycin, the second container must contain $9/5$ the quantity of chemical in Column E for that station since it will be necessary to introduce $1/5$ of the Column E value for 9 hours after the first hour's introduction.

Dilution should be done only with clean water to avoid potential problems with particulate matter plugging the pump or some of the fittings. De-chlorinated tap water is recommended since chlorine detoxifies rotenone.

The chemical pump is then preset, using clear water, to deliver at the rate of 5 gallons per hour (53 ml. in 10 seconds) and rechecked with a graduated cylinder at the project site before it is time to start the station. Needed minor adjustments are made at this time.

After the first hour of introduction has been completed at the computed rate, the quantity of chemical needed for the remaining 5 or 9 hours (all of which has also been diluted to 5 gallons in water) is dispensed from the second container by adjusting the pump to deliver at the rate of one gallon/hour for rotenone (63 ml. per minute) or at the rate of 0.55 gallon per hour (35 ml./min.) if antimycin is used.

Because these units have proven to be so trouble free, it is necessary only to see that they are operating properly and then check them periodically (every one or two hours) until delivery is complete. The savings on manpower by not having to continually tend these units readily pays for their initial cost.

Maintenance of the unit consists of thoroughly cleaning the pump after each project and recharging the battery. Because of the corrosive nature of salt and potassium permanganate, these chemicals are never dispensed through this equipment. Before storage, the pumps should be filled with clean fuel oil to protect their interior.

Applications of liquid formulations of fish toxicants from aircraft over lakes has resulted in some expensive failures (Gilderhus 1969). He reports that these failures include treatments with antimycin, rotenone and toxaphene, but concludes that fault may lie in the fact that the liquid is pressurized and discharged as a fine spray which, after further reduction in droplet size, reaches the water as a fine mist that is incapable of penetrating the surface film of the water.

Obviously, this potential for failure should be considered if aerial application of toxicants is planned for extensive backwater areas adjacent to the stream or in lakes that occur at the terminus of the project.

Smaller backwater areas are effectively treated by dispatching crews equipped with back pack spray cans. Treatment of these areas should coincide with the arrival of the toxicant prism in the stream.

Table 3 will serve as a quick guide to quantities of rotenone or antimycin required to treat off-stream ponds and backwaters.

BARRIERS TO UPSTREAM FISH MOVEMENT

Considering the time and expense involved in conducting stream reclamation projects, it seems inadvisable to treat streams which lack effective barriers (natural or man-made) against upstream movement of undesirable fish into the project area or to construct effective barriers.

McCoy and Ratledge (1967) recommend the Deibler or crib type barrier be constructed if no natural barrier is present. No comment on the effectiveness of these barriers is made.

Flick and Webster (1969) give detailed information for construction of an effective barrier panel suitable for installation immediately downstream from low head dams with a total height of not less than 30 inches.

Flick (1968) tested three types of fish barrier panels for use in conjunction with low head dams and found one type consisting of angled baffles lying parallel to the flow to be satisfactory even when water levels in the pool below the panel were 14 inches deep and the fish needed to jump only 16 inches high in order to pass over the barrier panel. Cost of the panel approached \$30.00 per foot (built on an existing dam) but were considered justifiable in view of the cost of a reclamation project.

In areas having sandy soils, it appears feasible to jet in a wall of Wakefield sheeting which extends 26 to 30 inches above the normal water level to serve as a low head dam below which barrier panels can be installed.

In any event, careful consideration should be taken of the expected maximum rise in water levels during periods of high stream flow and barriers should be designed to cover any reasonable possibility.

Further study of the practicability, effectiveness, feasibility, and economics of fish barriers of all types is badly needed.

Flick (1968) also observed that when dams had a vertical drop of 6 feet, or in situations where there was a steep gradient below the dam that was not favorable for jumping, adequate protection against upstream migration was provided.

DETOXIFICATION

Jackson (1957) observed that chlorine in the form of chlorinated lime and potassium permanganate were equally effective in detoxifying rotenone. He observed that in water which was relatively free from organic material, that the concentration of KMnO_4 or Cl_2 necessary to detoxify a given amount of rotenone in 24 hours was approximately the same as the amount of rotenone present in ppm.

Both chemicals are rapidly degraded in the presence of organic matter and in certain stream situations where large quantities of organic matter are present, a test for chlorine demand should be conducted and an additional quantity of these rotenone detoxicants added to satisfy this natural demand.

Lawrence (1956) reported immediate detoxification (essential in stream reclamation projects) of 1.0 ppm. Noxfish with 2.0 ppm. KMnO_4 at water temperatures of 44° to 68° F.

McCoy (1965) found that in the South Toe River (N.C.), concentrations of KMnO_4 up to 12 ppm. could be applied without apparent adverse effects on the downstream fishery.

It therefore seems evident that immediate detoxification of rotenone in water with low chlorine demands can be accomplished by introducing KMnO_4 at a concentration of not less than twice the rotenone concentration but not exceeding 12 ppm.

Detoxification of antimony in streams is a subject that is badly in need of further study. Detailed experimental information is completely lacking; however, Philip Gilderhus (U. S. Fish Control Laboratory, La Crosse, Wis., personal communication) has achieved successful detoxification of liquid antimony in field test by applying KMnO_4 at the rate of 2 ppm. for each 10 ppb. toxicant concentration present in streams with water temperatures below 60° F. and at 1 ppm. for each 10 ppb. toxicant concentration when temperatures exceeded 60° F.

In the absence of further study, I recommend that these interim recommendations be considered as minimum application rates. In all cases, block seines should be maintained across the stream several hundred yards below the detoxification station from the time the first suffering fish arrive until no dead fish are seen passing the detoxification station. Failure to stop the drift of dead fish downstream into untreated waters can result in considerable public misunderstanding and confusion.

The quantity of potassium permanganate required in detoxification of flowing water is calculated by . . .

$$\text{Pounds per hour} = (\text{ppm. desired})(\text{cfs.})(0.225)$$

Potassium permanganate is soluble in water at the rate of 0.5 pounds per gallon at 68°F.

Whenever possible, it is desirable that a KMnO_4 solution of known concentration (stock solution) be prepared in 55 gallon drums and dispensed at an established rate at the detoxification point.

Jackson (1957) reported that the loss of KMnO_4 in distilled water in the dark was insignificant over a 48-hour period.

The presence of a vehicular access to the detoxification point would permit premixing of the KMnO_4 solution using chlorinated tap water (assumed to be low in organic content and to have a satisfied chlorine demand) which would provide a relatively stable solution.

In the absence of vehicular access, stream water must be utilized. Because KMnO_4 may be rapidly lost in natural waters, mixing of the stock solution should be delayed until just prior to the time it is actually needed.

As noted earlier (see chemical prisms), erosion of both ends of the chemical prism results in long, sloping, leading, and trailing edges. These edges contain concentrations of chemical that should also be detoxified if damage to the fishery below the detoxification point is to be completely avoided.

Hence, in the above example, introduction of 10 ppm. KMnO_4 followed by 2 ppm. for an additional 5 hours would result in detoxification of most, but not all, of the arriving rotenone.

The following introduction schedule for stock KMnO_4 solution is recommended.

1. In order to neutralize the toxicant in the leading edge of the prism, begin introduction of 2 ppm. KMnO_4 not less than two hours before introduction of the 10 ppm. dose.

2. From salt-conductivity test, observe the expected time of arrival of the peak concentration of (5 ppm. for rotenone, 50 ppb. for antimycin) in the forward part of the prism. Subtract 30 minutes to find the time to begin introduction of 10 ppm. KMnO_4 .

3. Follow the introduction of 10 ppm. KMnO_4 with a minimum of 5 hours at 2 ppm. KMnO_4 followed by an additional 3 hours at 1 ppm. KMnO_4 for rotenone projects and by 10 hours of 2 ppm. and then 3 hours of 1 ppm. for antimycin projects.

DETOXICANT CALCULATIONS (Example)

In a flow of 13 cfs. total KMnO_4 requirements for rotenone detoxification would be:

$$\text{pounds/hour} = (10 \text{ ppm.})(13 \text{ cfs.})(0.225) = 29.25 \times 1 \text{ hr.} = 29.25$$

$$(2 \text{ ppm.})(13 \text{ cfs.})(0.225) = 5.85 \times 7 \text{ hrs.} = 40.95$$

$$(1 \text{ ppm.})(13 \text{ cfs.})(0.225) = 2.92 \times 3 \text{ hrs.} = \underline{8.76}$$

TOTAL POUNDS REQUIRED 78.96

Assuming that a stock solution of KMnO_4 is prepared by dissolving 18 pounds of KMnO_4 into 45 gallons of water (0.4 pounds/gallon), the rate of delivery of stock solution/hour to achieve any desired stream concentration of KMnO_4 is calculated by:

$$\text{gal./hour} = (\text{ppm. desired})(\text{cfs.})(\underline{0.56})$$

and in a flow of 13 cfs., delivery rates for the different stages of detoxification and the total requirements would be:

$$(10 \text{ ppm.})(13 \text{ cfs.})(0.56) = 72.8 \text{ gal./hour} \times 1 \text{ hour} \quad 72.8$$

$$(2 \text{ ppm.})(13 \text{ cfs.})(0.56) = 14.6 \text{ gal./hour} \times 7 \text{ hours} \quad 102.2$$

$$(1 \text{ ppm.})(13 \text{ cfs.})(0.56) = 7.3 \text{ gal./hour} \times 3 \text{ hours} \quad 21.9$$

$$\text{TOTAL REQUIREMENTS} = 197 \text{ gal.}$$

For antimycin detoxification, 108.21 pounds of KMnO_4 or 270.5 gallons of stock solution would be needed.

To provide for practical calibration of the flow rate, use any of the following formulas that will permit convenient measurement over the specified time period in containers which should be pre-marked for the project.

$$\text{ounces stock solution/minute} = (\text{ppm. desired})(\text{cfs.})(12.0)$$

$$\text{ml. stock solution/10 seconds} = (\text{ppm. desired})(\text{cfs.})(59.)$$

$$\text{ounces stock solution/10 seconds} = (\text{ppm. desired})(\text{cfs.})(2.0)$$

$$\text{gallon/minute} = (\text{ppm. desired})(\text{cfs.})(0.0093)$$

DETOXIFICATION EQUIPMENT

Equipment used to dispense the stock solution of KMnO_4 should be designed to provide for reasonably even distribution across the entire stream and should provide a constant rate of delivery.

Price and Haus (1963) have described a simple system for maintaining a constant flow of rotenone from a 55-gallon barrel. This system is also suitable for dispensing KMnO_4 solutions but because of its low rate of delivery (12 gal./hour maximum based on test of our units), its use with KMnO_4 is limited. At maximum flow, the system will only deliver sufficient KMnO_4 solution to treat 2 cfs. at 10 ppm., 10 cfs. at 2 ppm. and 20 cfs. at 1 ppm., pure KMnO_4 .

Application of stock solution at these rates to larger flows will require the simultaneous use of several barrels. For the single hour that 10 ppm. KMnO_4

is required, it may be more practical in large stream flows to calculate the pounds of KMnO_4 (dry) needed, divide it into 12 equal portions and apply one portion each 5 minutes by sprinkling it into the stream at the lip of the barrier or in a riffle to assist in mixing. The dry powder application method is considered to be potentially inaccurate and too tedious for long term treatments.

When impoundments having the capability of being drawn down to stream channel level terminate the project, detoxification can be simplified by sealing the dam as the toxicant prism arrives.

When the dam has been sealed a sufficient period of time to entrap the major portion of the arriving toxicant in the basin (6-8 hours for rotenone, 10-12 hours for antimycin), the quantity of KMnO_4 that would be needed to neutralize the toxicant in the stream is applied to the impounded water by placing the powder in several layers of burlap and pulling these bags behind a motor boat, being careful not to stir up the bottom sediment. Only the water seeping through the dam need be treated from a drip barrel and only until the impoundment is detoxified.

This latter approach, whenever possible, should always be used as it provides for the widest safety margin and requires much less equipment and manpower, especially when large stream flows are involved.

Regardless of the approach taken, this part of the project requires extremely careful planning to insure adequate, accurate and uninterrupted application of the required quantities of potassium permanganate.

Table 4 will give guidance as to the quantity of KMnO_4 required to detoxify off-stream ponds and backwaters, if necessary.

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APPENDIX

ROTENONE CALCULATIONS (Examples)

As noted earlier, when water temperatures exceed 60° F., rotenone can be expected to produce satisfactory fish kill when maintained at a peak of 5 ppm. for the first hour and followed by 1 ppm. for an additional 5 hours.

The format of Table 2 is recommended to assist project planners in conducting toxicant calculations and organizing the results. The following examples have been entered in Table 2.

FOR ALL STATIONS

Column A. Record the metered stream flow in cubic feet per second.

Column B. Calculate the ounces of rotenone required to treat this flow at the desired concentration (5 ppm.).

$$\text{ounces} = (\text{ppm. desired})(\text{cfs.})(3.456)$$

The value (3.456) is a constant.

Column C. Record the percent salt concentration introduced at this station which remained at the next downstream station. If for example, a 30 percent loss of concentration is experienced between Station 1 and 2, record 70 percent remaining in Column C for Station #1.

Note: Station #6 in this example represents the terminus of the project; therefore in the salt-conductivity test, no chemical was added, hence no retention figures are available or necessary.

Column D. Calculate and enter the quantity of chemical necessary at this station to give a 5 ppm. peak concentration at the next downstream station. $x = B/C$. For Station #1, use only C and B column values from Station #1 in the equation. For Station #2, use only C and B column values for Station #2 and so on up to but excluding the last station on the stream for which no calculations are necessary.

Column E. For Station #1 only, transpose the Station #1 D value into this column. This represents the quantity of rotenone/hour to introduce at Station #1 to insure a toxicant prism at #2 with a peak of 5 ppm.

For Station #s 2-5, we must consider the useable quantity of chemical arriving from upstream station. It is sufficient to note that all test and subsequent calculations have been designed to insure arrival of a peak of 5 ppm. to each station. It can be further observed that for any station, Column B provides a calculated point estimate of the instantaneous introduction rate necessary in the given flow to provide a 5 ppm. concentration.

For Station #2, we observe (Col. D) that 147.51 ounces of chemical/hr. are needed to provide 5 ppm. at Station #3. Since we have a peak concentration of 5 ppm. arriving at Station #2 from Station #1 in the form of useable toxicant prism, it will be necessary to add only the quantity of chemical calculated by subtracting the amount arriving at Station #2 (Col. B) from the total amount needed (Col. D, Sta. #2). $D - B = 147.51 - 120.96 = 26.55$ ounces of rotenone per hour must be introduced at Station #2 for one hour to reinforce the passing toxicant prism so that it will deliver a minimum peak concentration of 5 ppm. at Station #2.

In a similar manner, the Column E value is calculated for all remaining stations. For Station #3, it is observed that without considering the approaching prism, 172.80 ounces rotenone/hour would be required (Col. D). However, from Column B, Station #3, it is observed that 138.24 ounces of useable

chemical^{1/} is arriving in the approaching prism; so $D - B = 172.80 - 138.24 = 34.56$ ounces rotenone per hour is needed at Station #3 to reinforce the passing prism. In summary then, Table 2 values are derived as follows:

Station #1

Column A: metered flow in cfs.	5
B: (5 ppm.)(cfs.)(3.456)	86.4
C: salt conductivity test	70%
D: $x = B/C$	123.43
E: at Station #1 = D	123.43

Station #2

Column A: metered flow in cfs.	7
B: (5 ppm.)(cfs.)(3.456)	120.96
C: from salt conductivity test	82%
D: $x = B/C$	147.51
E: $D - B (147.51 - 120.96)$	26.55

ALL DOWNSTREAM STATIONS:

As shown for Station #2

To accomplish the required 1 ppm. introduction for an additional 5 hours, calculate 1/5 of the E column value for that station and introduce this quantity of chemical each hour for 5 hours.

^{1/} The author is aware that more than 138 ounces of chemical can be expected to arrive from Station #2. It is reasonable to assume that virtually all of the chemical introduced upstream (123.43 at Station #1 and 26.55 oz. at Station #2) or 149.98 ounces will eventually flow past Station #3. However, the useable portion of this total quantity includes only the amount of toxicant included in that portion of the prism with a lethal concentration of 1 ppm, or greater.

ANTIMYCIN CALCULATIONS (Examples)

As noted in the section on toxicant selection, when water temperatures are near or below 60°F., antimycin must be used in place of rotenone as a fish toxicant.

At present, three formulations of antimycin are available--Fintrol - 5, Fintrol - 15 (both sand formulations), and Fintrol Concentrate.

Fintrol Concentrate, the liquid formulation, has been shown to be of practical value in stream situations.

Each unit of Fintrol Concentrate consists of 480 milliliters of liquid of which 10% is antimycin and is prepared by the project biologist by mixing 240 ml. of Fintrol (48 grams of Antimycin A in 240 ml. of acetone) with 240 ml. diluent (dispersing agents dissolved in acetone).

Basic application rates are determined by the formula:

$$\begin{aligned} \text{ml. Fintrol Concentrate/hour} &= (\text{cfs.})(\text{ppb. desired}), \text{ since} \\ 1 \text{ ml./hr.} &= 1 \text{ ppb. in } 1 \text{ cfs.}^{2/} \end{aligned}$$

From salt-conductivity test, expected dilution rates of applied chemical concentrations can be defined as described earlier.

Problems involved in saturating the streams stored water reservoir were discussed in the section on chemical prisms and were solved for rotenone application by maintaining a reservoir of excess chemical in the forward portion of the prism.

A similar approach using antimycin would involve introducing sufficient antimycin at each station to establish a peak concentration in the forward portion of the prism equal to 5 times the desired minimum concentration of the following prism.

^{2/} Treatment of one acre foot of water at 1 ppb. requires 12.3 ml. Fintrol Concentrate. A 1 cfs. flow delivers 0.0826 acre ft./hour; hence 1.016 ml. of Fintrol Concentrate (12.3 x 0.0826) per hour is required to treat 1 cfs. at 1 ppb.

The format provided in Table 2 is applicable to antimycin and the reader is referred to the section "TOXICANT CALCULATIONS (ROTENONE)" for a discussion of the principles involved.

Very briefly, antimycin calculations for the same stream used in the rotenone example would be, assuming a 50 ppb. peak followed by 10 ppb. for 9 hours were desired:

Station #1

Column A: 5 cfs.

Column B: ml. antimycin/hr. at 50 ppb. = $(50 \text{ ppb.})(5 \text{ cfs.}) = 250 \text{ ml.}$

Column C: 70 percent retention

Column D: $x = B/C$; $x = 250/.70$; $x = 357 \text{ ml. antimycin}$

Column E: 357 ml. antimycin/hr. for first hour followed by 1/5 of that amount, or 71.4 ml./hr. for 9 consecutive hours.

Station #2

Column A: 7 cfs.

Column B: ml. antimycin/hr. at 50 ppb. = $(50 \text{ ppb.})(7 \text{ cfs.}) = 350 \text{ ml.}$

Column C: 82 percent retention

Column D: $x = B/C$; $x = 350/.82$; $x = 427 \text{ ml. antimycin}$

Column E: $D - B = 427 - 350 = 77 \text{ ml. of antimycin/hr. for the first hour followed by } 15.4 \text{ ml./hr. for 9 consecutive hours.}$

Station #3 yields a toxicant requirement of 100 ml. antimycin/hr. for one hour followed by 9 consecutive hours of 20 ml./hr.

Station #4 required 167 ml./hr. followed by 9 hours of 33.4 ml./hr.

Station #5 is 90 ml./hr. followed by 9 hours of introduction at the rate of 18 ml./hr.

TOXICANT CALCULATIONS INVOLVING MAJOR TRIBUTARIES

The format presented in Table 2 is ~~completed~~ for each major tributary exactly as outlined in the above section.

The Column B value for the terminal station on the tributary will estimate the amount of useable toxicant entering the main stream, and this value, along with the useable chemical arriving from further up the main stream must be considered in toxicant calculations for the main stream station located immediately above the mouth of the tributary.

For example, referring to Table 2, assume that it represents the main stream and that immediately downstream from Station #4, a major tributary entered. Also assume that for this tributary, calculations similar to those for the main stream revealed a final Column B value for the tributary of 21.5 ounces of rotenone. Thus we expect a useable quantity of 21.5 ounces of rotenone to join the main stream and reinforce the main stream prism just below Station #4. For Station #4, we have previously calculated (Col. E, Table 2) that 57.6 ounces/hour must be added to compensate for predicted loss downstream. Consideration of contributions from the tributary would reduce this value by 21.5 ounces giving a new column E value for Station #4 of 36.1 ounces/hour.

Note that only the Column E value for the main stream station immediately above the mouth of the tributary is affected. No other values require alteration.

Tributaries with flow values less than 10% of the main stream which they join may be considered minor tributaries at the option of the project biologist.

TOXICANT CALCULATIONS INVOLVING MINOR TRIBUTARIES

Minor tributaries with similar characteristics need not be examined in detail using salt-conductivity procedures. Their final contribution of useable toxicant to the main stream is relatively insignificant and it is only necessary to add sufficient toxicant to provide the necessary kill. One or more representative small tributaries should be examined to provide time and dilution data that could be applied to the other tributaries.

Table 1. Temperature factors for use in correcting resistance and conductance to 77 F.

<u>°F.</u>	<u>x Factors</u>		<u>°F.</u>	<u>x Factors</u>	
	<u>Resist.</u>	<u>Cond.</u>		<u>Resist.</u>	<u>Cond.</u>
38	.584	1.711	62	.830	1.205
39	.594	1.683	63	.840	1.190
40	.604	1.657	64	.852	1.174
41	.613	1.631	65	.862	1.160
42	.623	1.606	66	.873	1.145
43	.633	1.580	67	.884	1.131
44	.643	1.555	68	.894	1.118
45	.653	1.532	69	.906	1.104
46	.663	1.509	70	.917	1.090
47	.673	1.486	71	.930	1.075
48	.683	1.464	72	.942	1.062
49	.693	1.443	73	.954	1.048
50	.704	1.421	74	.967	1.034
51	.714	1.400	75	.978	1.023
52	.725	1.380	76	.988	1.011
53	.735	1.361	77	1.000	1.000
54	.745	1.342	78	1.011	0.989
55	.756	1.323	79	1.024	0.977
56	.766	1.305	80	1.035	0.966
57	.776	1.288	81	1.046	0.955
58	.787	1.271	82	1.058	0.945
59	.797	1.254	83	1.070	0.935
60	.808	1.237	84	1.081	0.925
61	.819	1.221	85	1.092	0.916

Adapted from L. A. Richards, The Diagnosis and Improvement of Saline and Alkali Soils. U. S. Dept. of Agriculture, Regional Salinity Lab., 1947

Table 2. Tabular presentation of calculations of quantities of rotenone required.

Station No.	A Flow in cfs.	B Ounces rotenone required to treat this flow at 5 ppm.	C % Salt concentrate introduced at this station remaining at next station	D $x = B/C$ Solve for x	E Ounces rotenone per hour to yield 5 ppm. at next station
1	5	$(5 \text{ ppm.}) (5 \text{ cfs.}) (3.456)$ 86.4	.70	$x = 86.4 / .70$ 123.43	D value 123.43
2	7	$(5 \text{ ppm.}) (7 \text{ cfs.}) (3.456)$ 120.96	.82	$x = 120.96 / .82$ 147.51	D - B 26.55
3	8	$(5 \text{ ppm.}) (8 \text{ cfs.}) (3.456)$ 138.24	.80	$x = 138.24 / .80$ 172.8	34.56
4	10	$(5 \text{ ppm.}) (10 \text{ cfs.}) (3.456)$ 172.80	.75	$x = 172.80 / .75$ 230.4	57.60
5	12	$(5 \text{ ppm.}) (12 \text{ cfs.}) (3.456)$ 207.36	.87	$x = 207.36 / .87$ 238.14	31.04
6	13	$(5 \text{ ppm.}) (13 \text{ cfs.}) (3.456)$ 224.64	terminus of project		

Table 3.

A. Quantities of antimycin required to give desired concentrations in off-stream ponds or backwaters.

<u>Acre feet standing water</u>	<u>Milliliters Fintrol Concentrate required to treat at 1 ppb.</u>	<u>Grams Fintrol-5 (1% antimycin by weight) required to yield 1 ppb.</u>
.5	6.0	63.5
1.0	12.3	127.0
2.0	24.6	254.0
3.0	36.9	381.0
4.0	49.2	508.0
5.0	61.5	635.0
10.0	123.0	1,270.0

B. Quantities of rotenone required to give desired concentrations in off-stream ponds or backwaters.

<u>Acre feet of standing water</u>	<u>Gallons of rotenone (5%) to treat at</u>				
	<u>1 ppm.</u>	<u>2 ppm.</u>	<u>3 ppm.</u>	<u>4 ppm.</u>	<u>5 ppm.</u>
.5	.17	.33	.50	.68	.85
1.0	.33	.66	1.00	1.33	1.66
2.0	.66	1.33	2.00	2.66	3.30
3.0	1.00	2.00	3.00	4.00	5.00
4.0	1.33	2.66	4.00	5.32	6.60
5.0	1.66	3.30	5.00	6.60	8.30
10.0	3.30	6.60	10.00	13.20	16.50

Table 4. Quantities of KMnO_4 required to give desired concentrations in off-stream ponds or backwaters.

Acre Feet Standing Water	Pounds KMnO_4 Required to Treat at				
	1 ppm.	2 ppm.	3 ppm.	4 ppm.	5 ppm.
.5	1.37	2.73	4.11	5.47	6.84
1.0	2.73	5.46	8.19	10.92	13.65
2.0	5.46	10.92	16.38	21.84	27.30
3.0	8.19	16.38	24.57	32.76	40.95
4.0	10.92	21.84	32.76	43.68	54.60
5.0	13.65	27.30	40.95	54.60	68.25
10.0	27.30	54.60	81.90	109.20	136.50

Figure 1. Relationship of salt concentration and resistivity at 77° F.

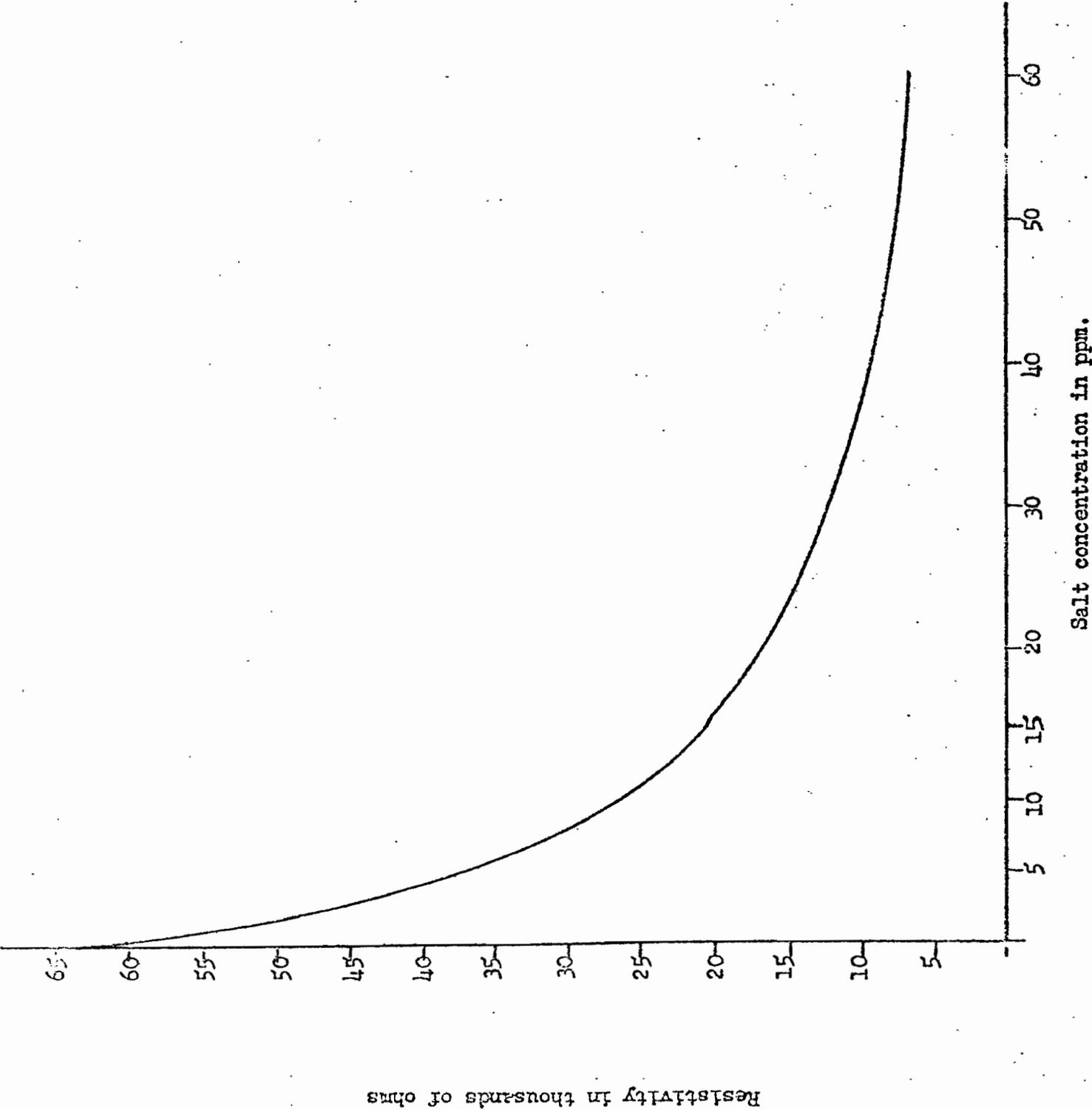


Figure 2. Regression of specific conductance on salt concentration at 77° F.

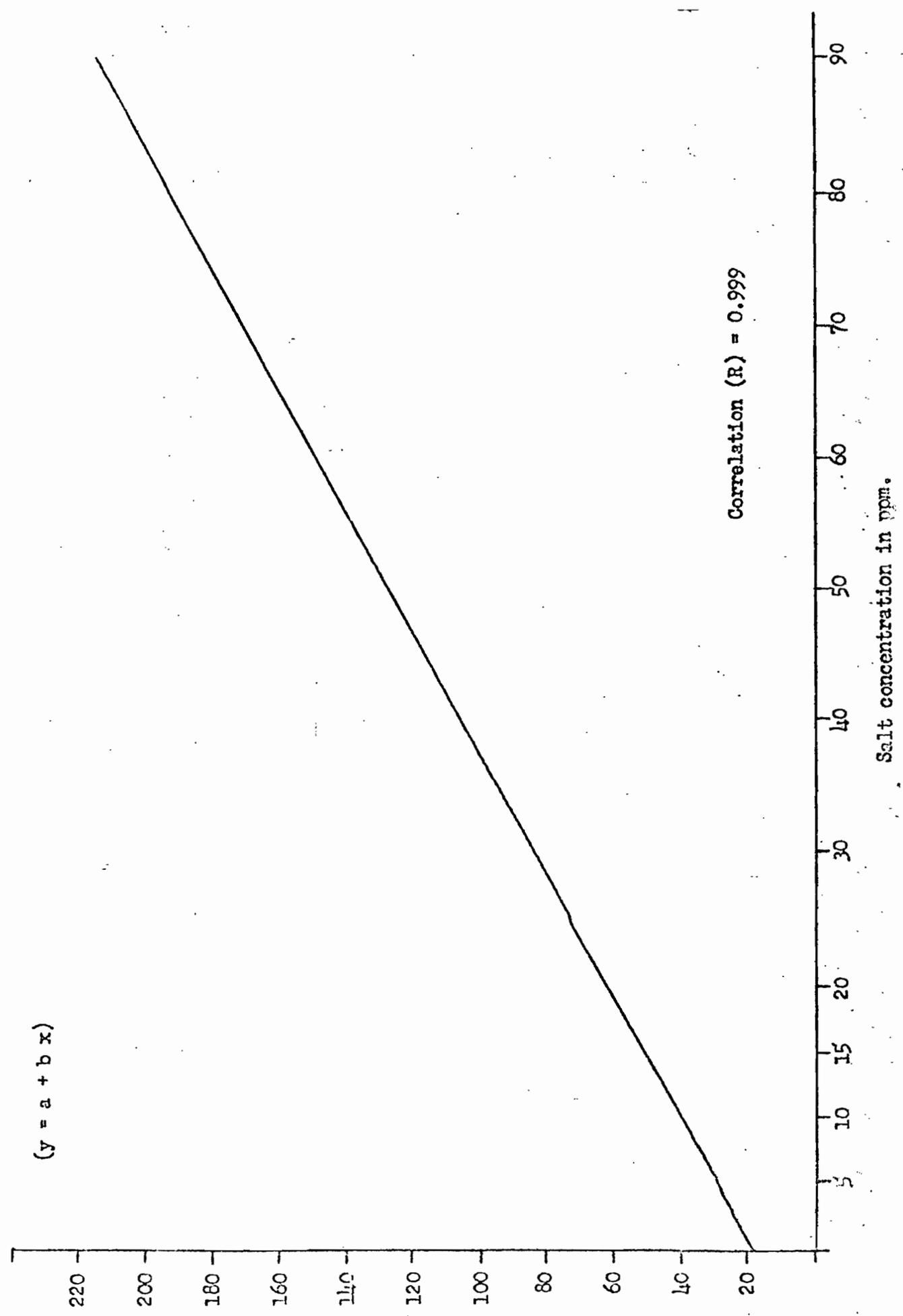
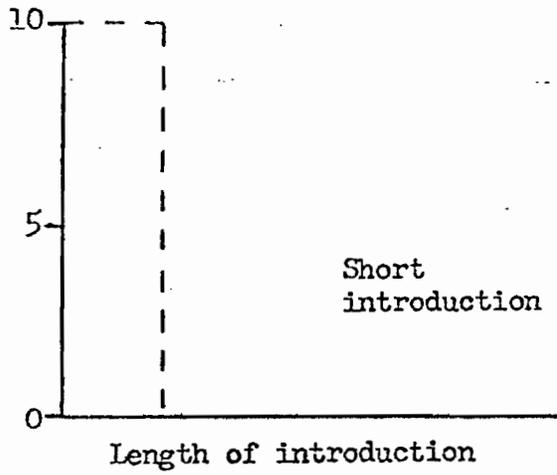
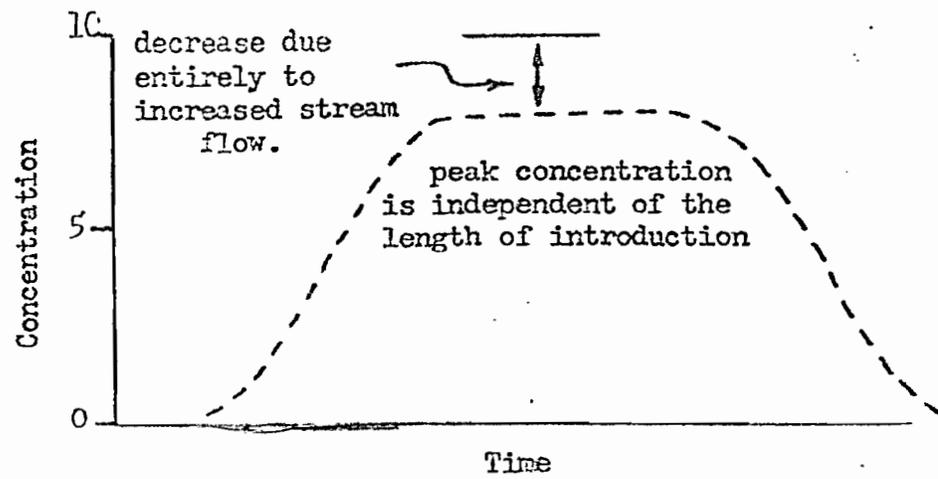
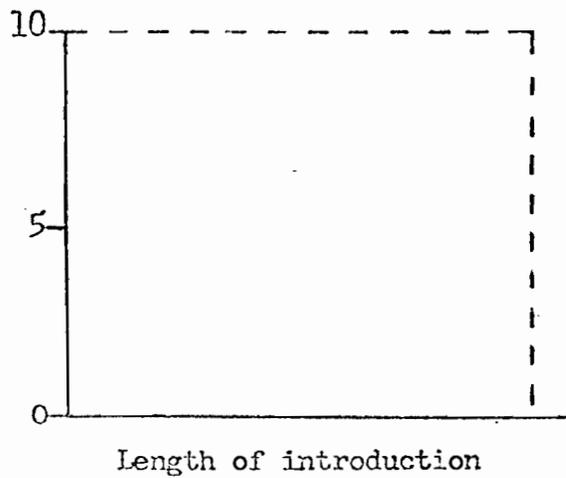
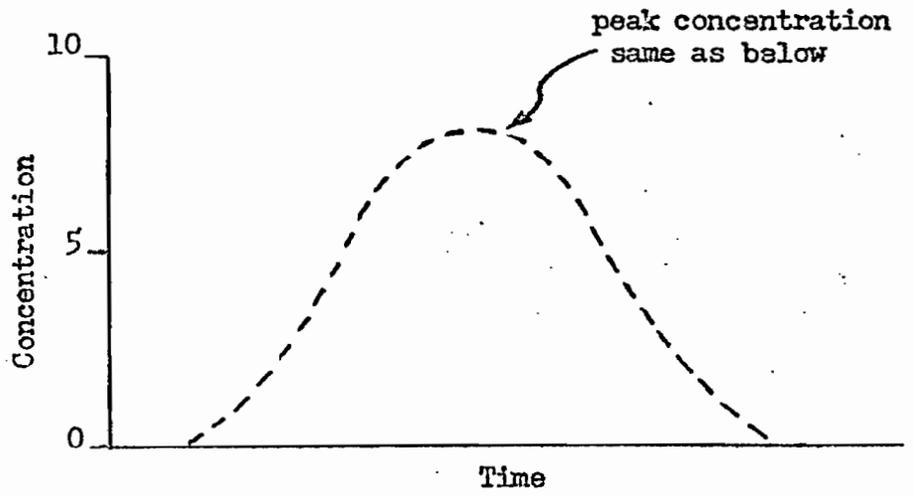
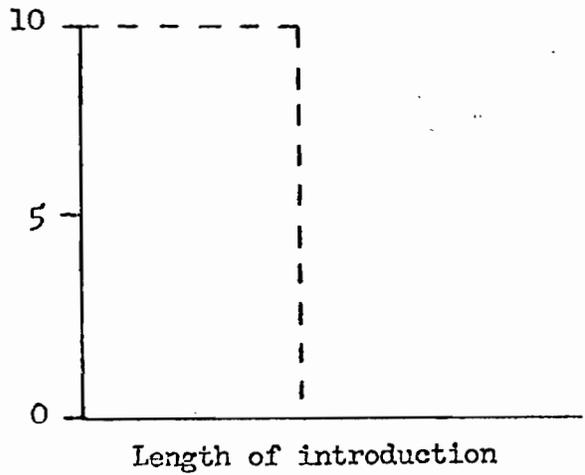
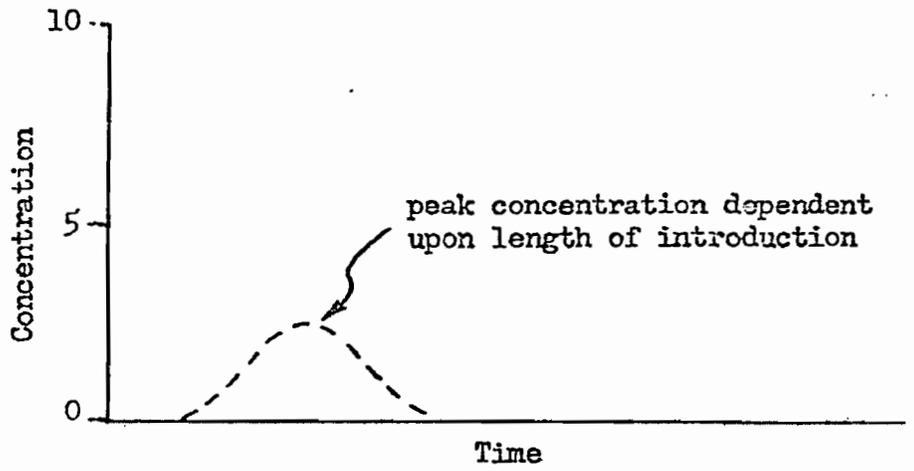


Figure 3. Effect of short tracer introduction on downstream prism dimensions.

Concentration at point of introduction



Concentration measured at downstream location



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