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MINIMIZING COST OF TRANSPORTING FISH FROM HATCHERIES TO PUBLIC FISHING WATERS[1]

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[1]Contribution from Dingell-Johnson Project F-35-R, Michigan

ABSTRACT

We developed and tested a computer system to help plan the transport of fish from hatcheries to public fishing waters. The objective of the system was to help manage the information needed for planning and to use that information to produce minimum-cost schedules for loading and transporting fish. We divided the problem into two parts, hatchery assignment and truck assignment. Under hatchery assignment, we used linear programming to assign planting sites to the nearest hatcheries. Under truck assignment, we developed an original algorithm to define planting trips and to assign the best type of truck for each trip. Our algorithm was able to define individual truck trips in which more than one site was planted or more than one species or size of fish was planted. Trucks were assigned according to their loading capacities, operating costs, unloading characteristics, and physical availability. The computer system has been used to help plan fish transportation by Michigan Department of Natural Resources since 1980. A number of problems were encountered in applying the system, but they were not unsurmountable. We think the computer system generated more efficient transportation schedules than manual planning methods, but we could not demonstrate this in a field test because confounding variables could not be controlled. However, we used the computer system to reschedule transportation for a group of fish that had been planted before the system was developed and found the computer-generated schedule could have accomplished the same fish plant 23% cheaper than the schedule actually used. If the distribution of fish production was shifted so that fish were reared closer to their planting locations, transportation costs could have been reduced 35%. The transportation system also allows managers to incorporate transportation costs into other management decisions, such as locating new hatcheries or evaluating the need for new trucks. The key to the future success of the computer system will be to keep adapting and refining it as new problems are identified and solved and new technologies allow for improved performance.

INTRODUCTION

At least once a year, fisheries management agencies face the problem of transporting fish from their hatcheries to public fishing waters. In Michigan, it involves delivering about 320,000 kgs of fish from six different hatcheries to about 2,500 stream and lake sites. The problem itself is easy to solve, almost trivial. All it takes is a fleet of fish-hauling trucks and enough time and manpower to load, drive, and unload the fish. Some planning is required to determine which hatchery will plant which stream or lake, but almost any plan will work. The number of workable solutions is nearly infinite.

However, one of the major factors distinguishing one plan from another is its cost. Obviously, it is best to transport the fish as cheaply as possible without jeopardizing their survival. In Michigan, total fish transportation costs are approximately $230,000 per year, so for each 1% improvement in transportation efficiency $2,300 per year in operating cost could be saved. But finding the cheapest solution, or even one of the cheapest, is difficult. The only practical way to do it is to use computerized optimization procedures.

We developed and tested a computer system to help plan fish transportation in Michigan. The objective of the system was to help manage the information needed for planning and to use that information to produce minimum-cost schedules for loading and transporting hatchery fish. In this report, we will describe the computer system, the results of its application, and the potential for its use in the future.

THE SCOPE OF THE PROBLEM IN MICHIGAN

Fishes produced in Michigan hatcheries are primarily coldwater species. Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*Oncorhynchus kisutch*), Atlantic salmon (*Salmo salar*), steelhead (*Salmo gairdneri*), splake (*Salvelinus* sp.), and lake trout (*Salvelinus namaycush*) are usually planted in the Great Lakes. Brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), and rainbow trout (*Salmo gairdneri*) are usually planted in smaller lakes and streams. Often, several strains and size categories of the same species are produced to meet specific management needs. For example, six strains of rainbow trout were produced in 1984 (including five strains of steelhead), and it is not uncommon to produce four size categories of brown trout each year, from fingerlings to adults.

These fish are produced at six hatcheries (Fig. 1) and must be delivered to about 2,400 different sites. Total annual production of these coldwater species is approximately 300,000 kgs per year. About 90% of the fish are planted in the spring, from March to June, and most of the remainder are planted in the fall, from September to November.

Four types of fish transport vehicles are used. In general, the larger the vehicle the more fish it can haul per trip, but the less flexible it is in its unloading capabilities and the fewer sites it can reach due to road access conditions. Also, the operating cost per km driven increases with vehicle size. Semi trucks are the largest, carrying up to 2,270 kgs of fish in a single haul. They consist of a tractor and detachable trailer and have an operating cost of $0.182 per km (based on fuel consumption only). The trailer unit contains one continuous fish tank which is unloaded through a valve-tube assembly. All the fish must be unloaded at a single site, and good road access is needed to accommodate the large vehicle. Semi trucks are used almost exclusively to make large plants at Great Lakes sites.

Next in size are Peterson trucks. They can carry up to 1000 kgs of fish per haul for a cost of $0.104 per km. Their fish tank is divided into four separate compartments. Thus, it is possible to haul four different species, sizes, or strains of fish at the same time without mixing them. Also, these fish could be delivered to a number of different planting sites in a single trip, because it is possible to unload a single compartment, or fraction thereof, with scap-nets. Next in size are Manchester trucks. Their maximum capacity is about 400 kgs per haul at $0.101 per km. Their fish tank is divided into three compartments, and they can also be used to deliver fish to a number of planting sites in a single trip. Finally, small, four-wheel-drive pickup trucks are sometimes necessary to get fish to the more remote planting sites. These planting sites are not very numerous, but they require special attention and coordination between hatchery and field personnel. Loading capacities and costs for planting these sites vary with site characteristics.

Most species and size categories of fish have unique metabolic rates, and the loading capacities of transport vehicles must be adjusted accordingly. For example, it might be possible to safely transport 2,000 kgs of yearling brown trout in a semi truck, but only 1,000 kgs of fingerling brown trout could be transported in that same truck. The reason is that the smaller fish have a higher metabolic rate and deplete the oxygen in the transport tank faster.

The number and type of fish required at each planting site varies tremendously. Some sites require several truckloads of fish, while others require just a few buckets full. Some require a mixture of species or strains, while others require several size categories of the same species. The characteristics of the sites themselves also varies tremendously. One site might be a small, remote stream or lake with limited road access, while another might be the docking facility of a large city on the Great Lakes.

Coordinating fish transportation activities is the responsibility of a single manager (fish planting coordinator). He acts as planner and dispatcher of trucks to the hatcheries, coordinates truck movements between hatcheries, oversees vehicle maintenance, and maintains records of cost and effectiveness of the transportation program. The individual hatchery managers plan the loading and delivery of fish after receiving their allotment of trucks. The coordinator and the primary vehicle maintenance shop are centrally located at the Platte River Hatchery (Fig. 1). This location allows the coordinator to monitor day-to-day activities and to make the critical decisions necessary to overcome the everyday problems typical of such an operation.

The system of computer programs we developed helps the planting coordinator and hatchery managers plan efficient transportation schedules. We named it the Michigan Fish Transportation System. Our system is part of a much larger system called the Fish Stocking Information System (Fig. 2). We will not describe the details of this larger system except to say that most of it is computerized and that it is continuously evolving as new problems are identified and solved. By this means, the system becomes more automated and is improved through time.

THE MICHIGAN FISH TRANSPORTATION SYSTEM

From the description above it is easy to see the complexity of the fish transportation problem. Business management and operations research methods such as linear programming can help minimize the cost of transportation, but a complete solution is not possible with these standard methods. There are too many unique factors and exceptions to the rules. To make the problem more tractable, we divided it into two parts or subsystems, hatchery assignment and truck assignment. In the hatchery assignment part, we used linear programming to assign planting sites to hatcheries. The basic job was to assign sites to the closest possible hatchery considering the number, size, and species of fish needed, and which hatcheries were producing that type of fish. In the truck assignment part, we developed an original optimization algorithm to define planting trips and to assign the best truck for each trip. Our algorithm was able to define individual truck trips in which more than one site was planted or more than one species or size of fish was planted. Trucks were assigned according to their loading capacities, operating costs, unloading characteristics, and physical availability.

Hatchery Assignment

The hatchery assignment problem can be represented as a typical business transportation problem (Hiller and Lieberman 1974). The linear programming format is:

Minimize X where,

$X = \Sigma \Sigma (C_{ij} F_{ij})$

C_{ij} = distance between hatchery "i" and site "j",

F_{ij} = number of a given species of fish produced in hatchery "i" and planted at site "j".

Subject to,

(1) Hatchery constraints (one for each hatchery)

$\Sigma F_{ij} = P_i$

P_{ij} = total number of the given species to be produced in hatchery "i".

(2) Planting site constraints (one for each site)

$\Sigma F_{ij} = S_j$

S_j = number of the given species to be planted at site "j".

(3) Non-negativity constraints

All C_{ij}, F_{ij}, P_{ij}, and $S_j \geq 0$.

Given the production for each hatchery, numbers of each species to be planted at each site, and distances between hatcheries and sites this model can be used to determine how many fish each hatchery should deliver to each site. The solution found by this algorithm will be the one with the shortest total driving distance, and assuming cost is directly related to the total distance driven, it will also be the cheapest solution.

We used the simplex method to calculate a solution to this problem (Hiller and Lieberman 1974). It is the most common method of solving linear programming problems. Most university computing centers have access to programs using the simplex method, but we used a program subroutine, named LINEAR, written in FORTRAN by Don McCarty of Texas Parks and Wildlife Department.

The major disadvantage of the simplex method was that its matrix structure restricted the practical size of the problem it could solve. To help understand the severity of this restriction, consider the problem of assigning planting sites to hatcheries for yearling brown trout in Michigan. In any given year, brown trout could be reared in five different hatcheries, and they could be scheduled for planting at 800 sites. This defines a linear programming problem with 4,805 variables in its objective function and 805 separate constraint equations. The matrix used in the simplex method would contain (805) x (4,805) = 3,868,025 elements. Only a few of the largest, fastest computers in the world could handle a matrix of this size for a practical cost and execution time.

We developed a computer program to reduce the number of planting sites going into the simplex algorithm by combining some sites into site clusters. Sites that were close in distance to one another were combined and then considered as a single site by the simplex algorithm. This compressed the hatchery assignment problem so it could be solved by most mainframe computers (maximum matrix size was 222,811).

The Hatchery Assignment Subsystem is illustrated in Figure 3. The central element of the subsystem is the DISTRIBUTE program (highlighted). The output of the program is the

Optimal Planting Strategy (Table 1). The linear programming approach described above is used to arrive at this strategy.

The other programs, TRIANGLE, CLUMP, and SPLIT (Fig. 3), perform data management functions. The TRIANGLE program is used to update and expand the Main Site File. This file contains the name, location, and description of all planting sites and their relative distances to each of the hatcheries. The location of each site is defined by an already-existing statewide grid system, the Town-Range-Section System, in which each square mile of the state is given unique coordinates within a grid.

The grid system is an essential part of the overall computer system. It avoids the need to manually measure thousands of individual distances on road maps, because it enables the computer to calculate straight-line distances between any two points by the Pythagorean Theorem. We refer to these distances as relative distances, because they are not equal to actual driving distances. However, we found they were highly correlated with driving distances ($r = 0.98$), and this means the linear programming algorithm will produce nearly the same Optimal Planting Strategy using either the relative or the actual driving distances.

Program CLUMP retrieves all the information for sites to be planted from the Main Site File and creates a smaller file of active sites (Active Site File). It also performs the job of combining sites into site clusters or psuedo sites (Psuedo Site File). This is accomplished by choosing central planting sites (pivotal sites) and combining the fish to be planted there, with those to be planted at all other sites within a specified distance or cluster radius. Obviously, as greater distances are specified more sites are combined into each cluster and fewer psuedo sites are produced. Fewer psuedo sites result in a smaller linear programming problem for DISTRIBUTE, as described above. However, creating large-diameter pseudo sites also reduces the optimality of that linear programming solution, because driving time and distance within the site clusters increases when clusters are spread over large areas. We found that site clusters of about 30 km in diameter worked best.

Program SPLIT divides the site clusters back into their original single-site form and creates the Super Site File (Fig. 3). This file is used later to develop truck assignments. It contains all the information for sites to be planted from the Main Site File, as well as, the Optimal Planting Strategy. That is, the number of fish to be supplied by each hatchery is added to the records for each site.

Truck Assignment

The Truck Assignment Subsystem is illustrated in Figure 4. The central element of the subsystem is the DISPATCH program (highlighted). The function of DISPATCH is to minimize cost of delivering fish from the hatcheries by defining efficient loads and destinations for each truck trip. It does this based on the weight and type of fish required at each planting site, the distances between planting sites (deliveries to sites in the same vicinity might be combined into one trip), and the operating cost, loading capacities, and availability of each truck type in the fleet. The input for DISPATCH relating to the fish planting requirements (Loads File) is organized by program SCHEDULE (Fig. 4) which also converts numbers of fish into weights (the Hatchery Assignment Subsystem deals with numbers of fish) and identifies sites requiring more than one species or size category of fish. Input concerning the characteristics of the truck fleet are entered separately. These include the current operating cost and loading capacities of each type of truck and the number of trucks available. The outputs of DISPATCH are load and trip assignments for each hatchery and truck type (Table 2) and a relative cost for planting all the fish.

Standard optimization procedures could not be applied to this problem, so we devised our own procedure using simple logic. Our basic assumption was that the cheapest way to transport any load of fish is to use the smallest truck available that is capable of carrying the load in a single haul. In other words, it is always cheaper to make a delivery in a single trip with a small truck filled to capacity than with a large truck only partially full, and it is always cheaper to make a delivery in a single trip with a large truck than to divide the load and make the delivery in a number of trips with smaller trucks.

The DISPATCH computer program does about the same thing a human planner would do by hand if given the task. First, it defines semi-truck trips. Loads of fish are allocated to semi trucks if: 1) they are single-species and single-site deliveries, 2) the planting site has no access restrictions, and 3) they cannot be taken by a smaller truck in a single trip. Second, it defines Peterson truck trips, and third, it defines Manchester truck trips. Loads of fish are allocated to the latter two trucks if: 1) the planting site (or sites) has no access restrictions for the given truck and 2) they cannot be taken by a smaller truck in a single trip. The program might define loads containing more than one planting site or species of fish for Peterson and Manchester trucks. For example, the fourth Peterson truck trip listed in Table 2 goes to two planting sites, Louise Lake and the Maple River, and contains two species of fish yearling, brown trout (BNT Y) and Michigan-strain splake (SPM Y).

DISPATCH develops multiple-site deliveries the same way CLUMP developed site clusters. It selects a pivotal site and then searches for other sites within a specified distance. It keeps adding new sites to the load until either the truck is filled to capacity or a specified limit in number of sites per truck trip is reached. We found that a maximum of 10 to 12 sites per truck trip was best from the standpoint of time and cost efficiency. With regard to time, it is difficult for a truck driver to make more than 12 planting stops in a single day's trip. We will present an analysis of cost efficiency in another section of this report.

The relative cost of each planting scheme, which is an output of DISPATCH, allows the comparison of the cost efficiency of alternative schemes before they are actually carried out. It is calculated as follows:

$$\text{Relative cost} = (T_1)(C_1)(D_1) + (T_2)(C_2)(D_2) + (T_3)(C_3)(D_3)$$

where T_i is the number of trips taken, C_i is the operating cost, and D_i is the total relative distance driven by truck type i. This relative cost cannot be used as an actual cost estimate for transporting the fish because the relative distances are not measures of road miles. However, the relative cost of alternative planting schemes should be proportional to their actual costs.

APPLYING THE SYSTEM

The computer system was first used to help plan fish transportation in 1980, when an early version of the system was used to schedule planting of salmonids in the Great Lakes. Results of this initial test were generally favorable, but the planting coordinator found it difficult to integrate the computer-generated planting schedule for the Great Lakes with the manually generated schedule for inland waters. In 1981, the computer system was expanded to cover both Great Lakes and inland plants but was only used to schedule part of the fish plants that year. Final approval of planting requests for some sites was delayed, and the planting of sites receiving early approval had to begin. All the sites to be planted in a given season must be known before the computer system can be used. Delays in approval of planting requests became a persistent problem over the years, but there were other problems also. In 1982, the computer system was used to plan fish transportation, but, once again, for only part of the plants. Large fish kills occurred in the hatcheries, about midway through the planting season, making the final half of the computer-generated schedule useless. It was not possible to rerun the computer system in time to generate a new schedule. In 1983 and 1984, computer scheduling of fish transportation was fairly successful with only minor problems occurring.

However, in 1985, a number of major problems occurred which precluded the use of the computer scheduling system. There were delays in approving fish planting requests, numerous mechanical breakdowns of trucks, and increases in fish production which exceeded the capacity of the existing truck fleet. Furthermore, dissatisfaction had developed among hatchery managers in the load and trip assignments generated by the DISPATCH program. This dissatisfaction was due primarily to the inability of the computer program to handle differences in sizes of fish produced at different hatcheries. For example, the average weights of each kind of fish are part of the input (Loads File) for DISPATCH. The weights are needed to calculate proper load sizes for each type of truck. When the size of the fish at a given hatchery is not near the average size at the other hatcheries, then the truck load sizes are incorrect for that hatchery. This problem also occurs to some extent through the 3-month-long planting season because the fish grow in size. A solution to this problem is being devised and will be discussed later. In 1986, the computer was used to assign planting sites to hatcheries, but the loads and truck trips were done manually.

We think the computer system generated more efficient transportation schedules than manual planning methods, but we could not demonstrate this in a field test. The ideal way to evaluate efficiency would be to compare transportation costs before and after the computer system was used. Unfortunately, we could not do this because the real-world management system was too complex and we could not control many of the important variables. During the period we were testing the computer system, major renovations of hatchery rearing facilities were conducted which affected the total number and location of fish produced in some years; Peterson fish planting trucks were gradually phased into use to replace older, mid-sized trucks; and dramatic increases occurred in the costs of truck fuel, maintenance, and manpower. Other performance measures, such as average weight transported per truck trip, average weight transported per kilometer driven, or average length of a truck trip, could not be compared either because they are also affected by the distribution of fish production and the composition of the truck fleet.

Although a measure of efficiency in a field test was not possible, we did evaluate the potential of the computer system in a more theoretical manner. We used it to reschedule transportation for a group of fish that had been planted before the computer system was developed. Then we compared the computer-generated schedule to the schedule that was actually used. This was done for two scenarios. The first was to redo the schedule without changing the distribution of fish production among hatcheries. The second was to redo the schedule after making some hypothetical shifts in the distribution of fish production. The idea in this second scenario was to determine how much could be saved in transportation costs if the fish were reared at hatcheries which were closer to their planting locations. The 1979 plant of salmon, steelhead, and brown trout in the Great Lakes was used for this exercise. We used actual road distances in the computer system instead of relative distances, so the distances driven and costs of the real and hypothetical schedules could be compared directly.

Results of the first scenario suggested we could have reduced the cost of transporting these fish by 23%, if the computer system had been used in 1979. Total cost (in fuel and oil only) of the actual planting was $6,935 versus a theoretical cost of $5,334 for the computer-generated schedule. The computer system was more efficient because it greatly reduced the distance traveled by smaller trucks while only slightly increasing the distance traveled by semi trucks (Table 3). Results of the second scenario suggested that the cost of transportation could have been reduced even further to $4,484 (a total savings of 35%) if fish were reared closer to their planting locations.

The transportation system can also help managers incorporate transportation costs into other management decisions or study some of the details of the transportation problem. For example, it could be used to help locate new hatcheries, to evaluate the need for new trucks, to determine the benefits of carrying multiple-species loads instead of single-species loads, or to determine the benefits of changing the number of sites per truck trip. Such analyses require describing decision alternatives in terms of system inputs and comparing relative costs of each alternative. For example, Figure 5 shows the relationship between the cost of planting yearling brown and rainbow trout for a typical year and the maximum number of planting sites allowed per truck trip. Cost decreased exponentially as sites per trip increased, never going below $2,500. A point of diminishing returns was reached between 10 and 12 sites per trip, so increasing the number of sites per trip above 12 could not be justified based on savings in transportation costs. We cannot place a value on the ability to study the details of the system in this manner, but, over the long term, the insight gained might be even more valuable than the cumulative yearly savings obtained from generating efficient truck schedules.

DISCUSSION

The main question we must answer is whether or not computer-assisted planning of fish transportation is better than manual planning. We think the answer is yes. When direct comparisons were made, as in our example of the 1979 Great Lakes plants, we found the computer-generated schedules could have accomplished fish planting cheaper than schedules generated by manual methods. Also, the ability to study details of the transportation problem with the computer system appears to be of great value.

The problems we encountered in applying the system are solvable. The three biggest problems were: 1) delays in obtaining approval of planting sites, 2) the inability to quickly rerun the programs after a fish kill, and 3) the inability of the DISPATCH program to handle differences in fish size among hatcheries. To help solve the first problem, another computer system has been developed by Fisheries Division staff in Lansing to process the large number of planting requests more rapidly. Also, a new timetable for fish planting was devised to ensure that the requests will be processed in time to plan a transportation schedule.

The solution to the last two problems is to revise the DISPATCH program so it can be run and rerun as needed at each individual hatchery. We designed the initial system to be run in batch mode on a central mainframe computer because, at the time, it was the only feasible way to handle the problem. Now we have powerful microcomputers located at all of our hatcheries, and the Fish Transportation System should be redesigned to take full advantage of the new technology. Instead of using a central computer to define truck loads and trips for all the hatcheries and for the entire planting season, each hatchery manager could run and rerun the program as needed on their own microcomputer. The numbers and sizes of fish in each hatchery could be revised and updated on a daily basis if necessary.

The key to the future success of the transportation system will be to keep adapting and refining it as new problems are identified and solved and new technologies allow for improved performance. There will always be a need for central control and planning, but the computer programs should be rewritten as "user-friendly" tools and should be used directly by the people closest to the problem. Ideally, the fish planting coordinator and the hatchery managers should be able to run the entire system after getting approved fish planting sites from Lansing staff. Such an ideal system might not yet be possible with today's computer technology because of the limitations in program size and computing speed of our current microcomputers. However, improvements in computer technology are still occurring at a rapid pace. It has been projected that within 2 years the next generation of microcomputers will be available (Crecine 1986). These machines are expected to be 5 to 10 times more powerful than current machines for about the same price, with 10 to 20 times more active memory and 2 to 5 times faster execution speeds. There seems to be little doubt that in the near future the entire Fish Transportation System could be run on a desktop computer.

Our computer system and experience in using it might be useful to other agencies with similar transportation problems. The general approach we described could be used in any hatchery program to help improve planning and efficiency of fish transportation. Most of the computer programs we developed are too specific to Michigan's problem to be applied directly to another hatchery program. However, most fish transportation problems are similar enough that a knowledgeable programmer/analyst could modify our system to satisfy the needs of another hatchery program, or use it as a guide to develop a new system.

ACKNOWLEDGMENTS

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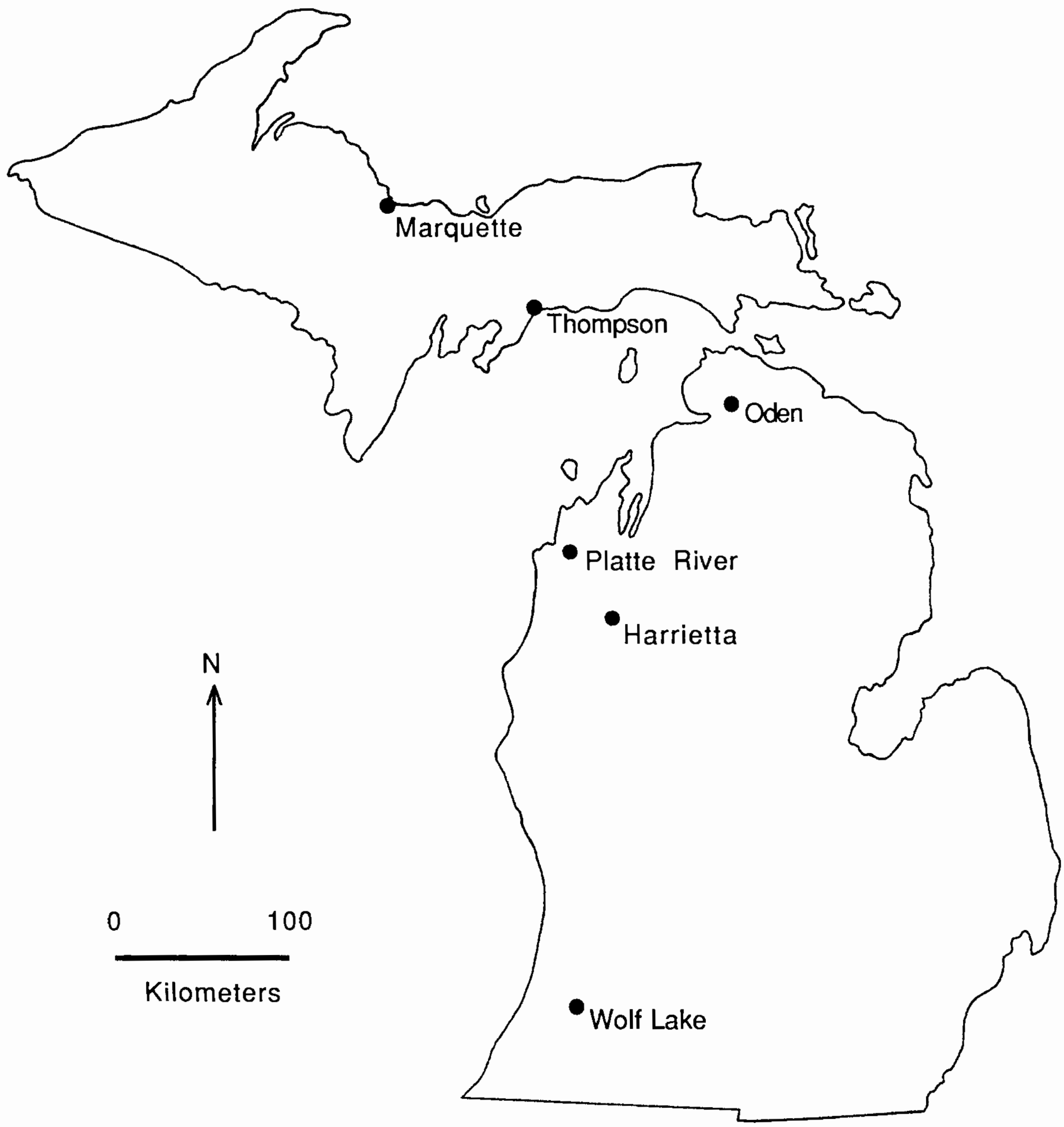

Figure 1. Location of fish hatcheries operated by the State of Michigan.

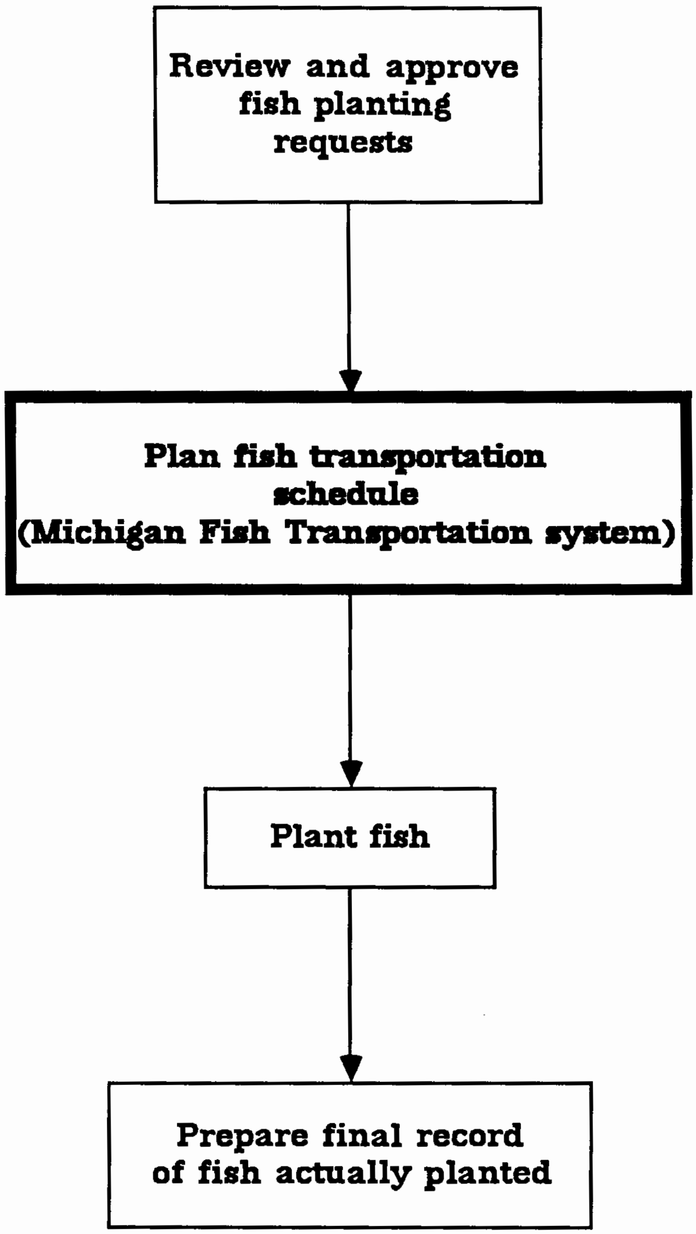

Figure 2. The Fish Stocking Information System used by Michigan Department of Natural Resources. Michigan Fish Transportation System is highlighted.

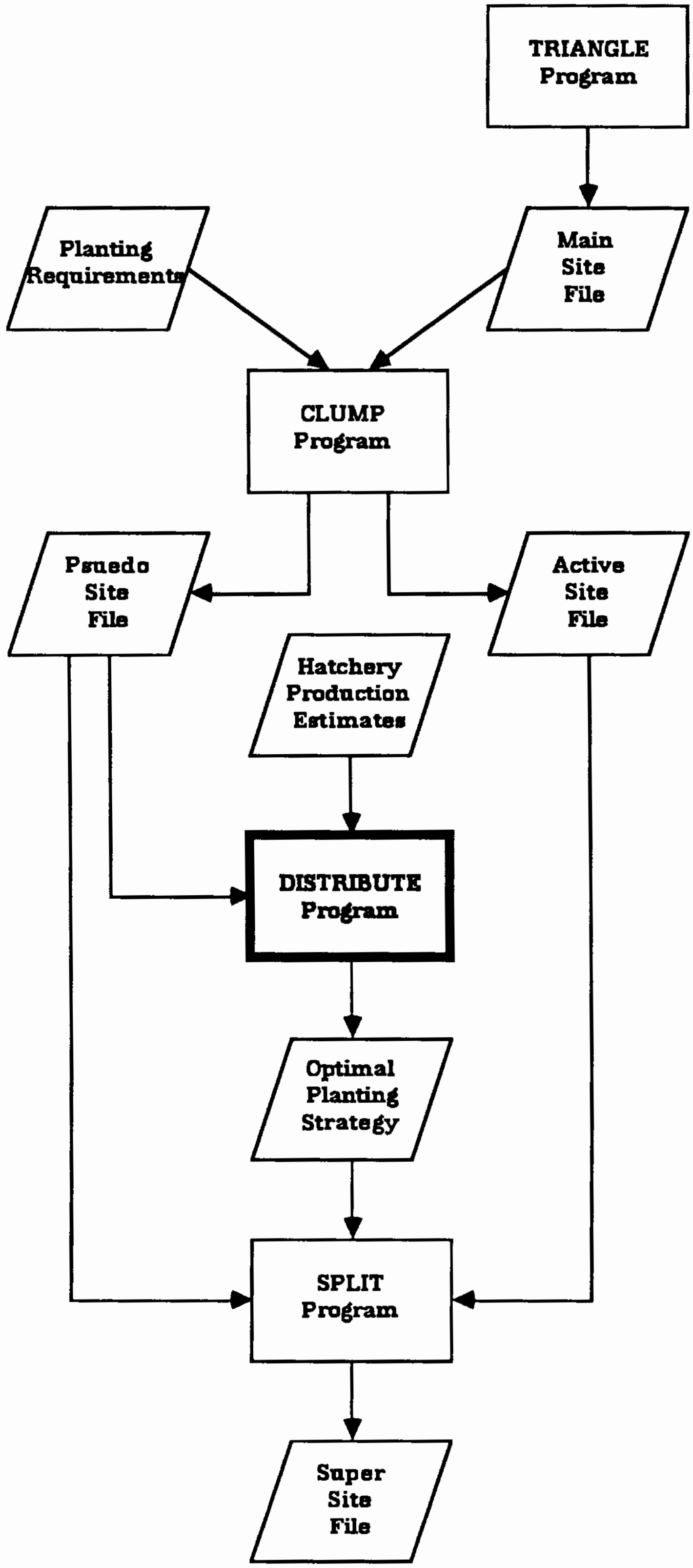

Figure 3. Subsystem to assign planting sites to hatcheries.

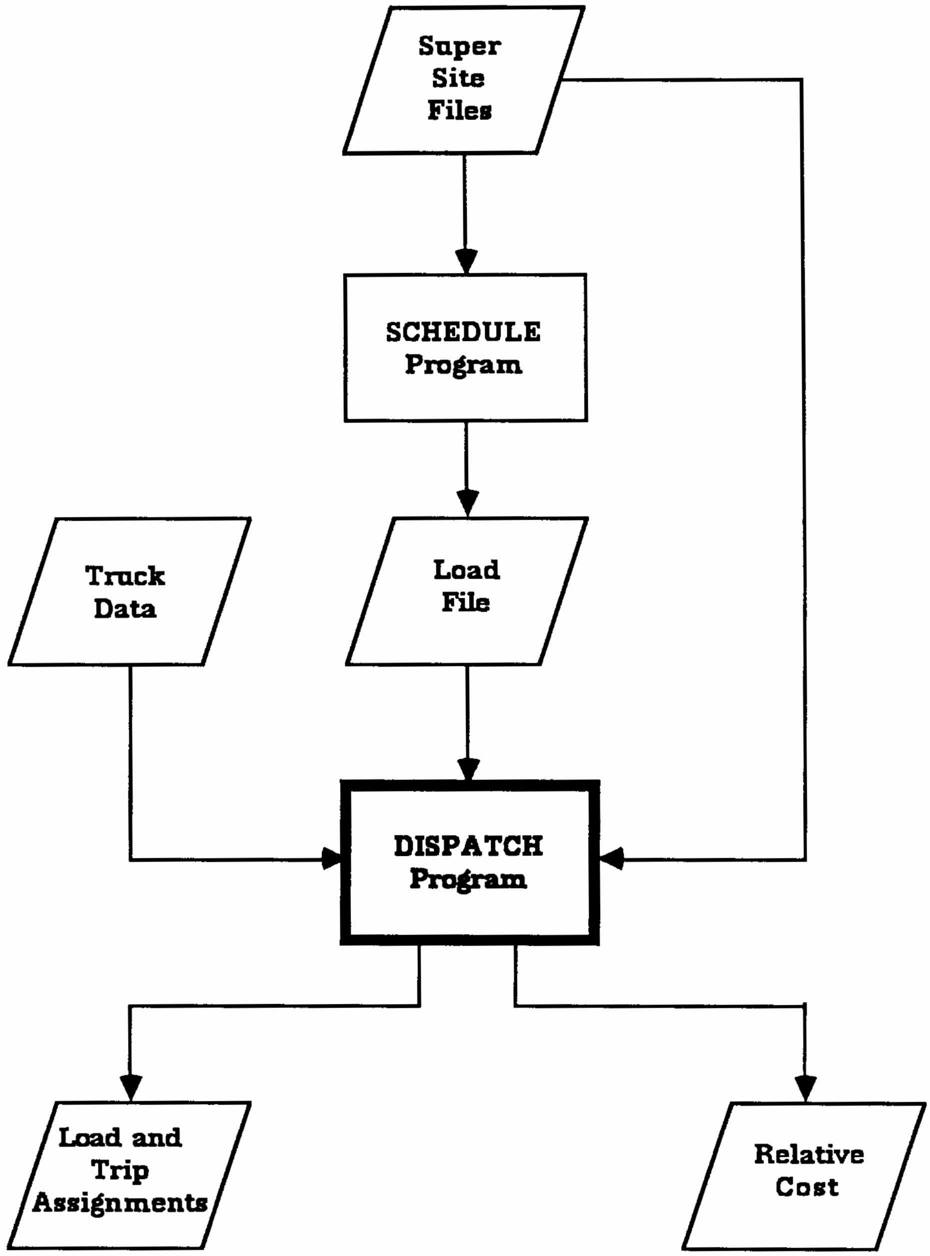

Figure 4. Subsystem to assign loads and trips to trucks.

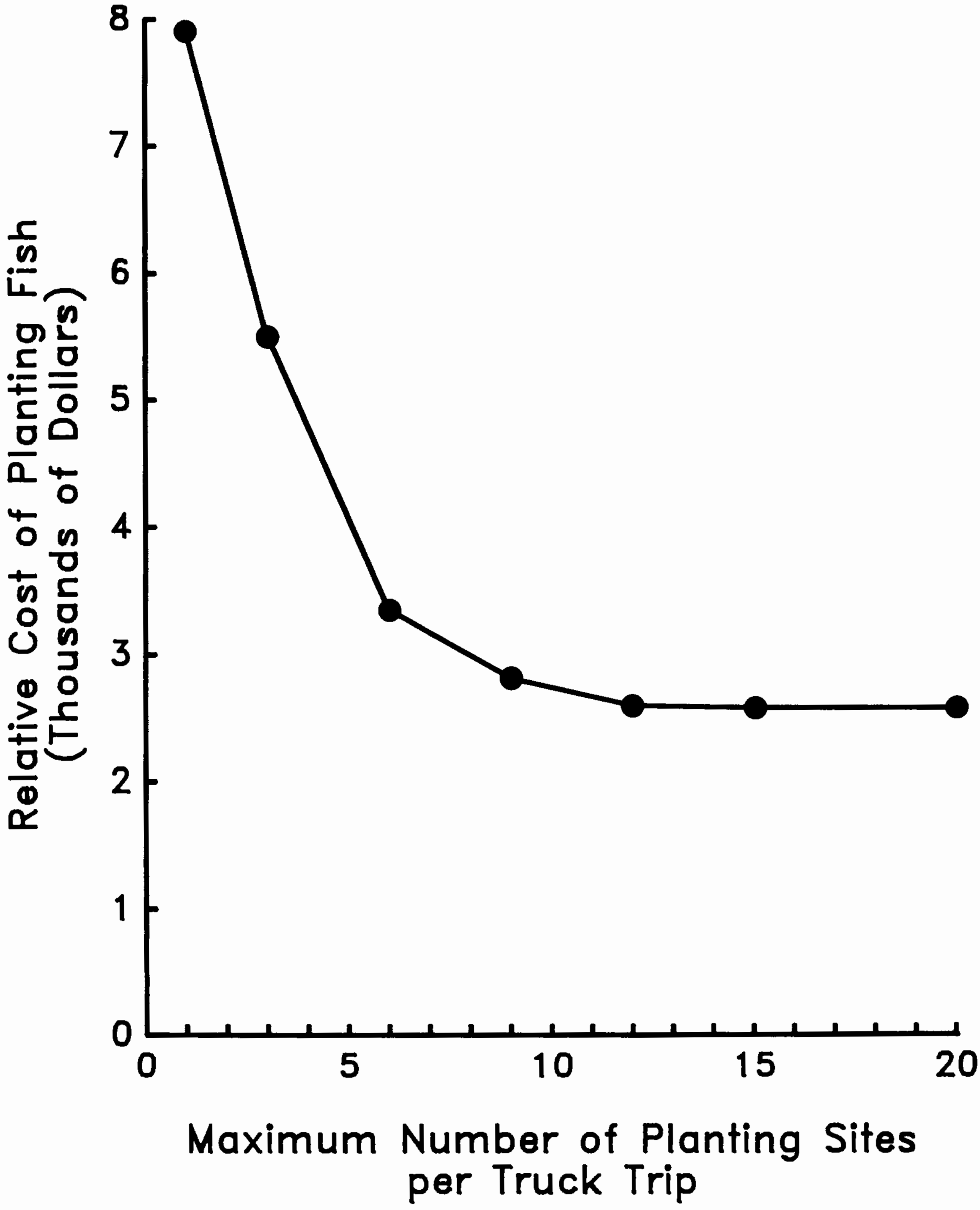

Figure 5. Relative cost versus maximum number of planting sites per truck trip for yearling brown and rainbow trout.

Table 1. Part of the Optimal Planting Strategy for yearling brown trout in Michigan for spring of 1983. The entire Strategy contained a total of 543 planting sites.

Planting site		Number of fish supplied by hatchery					
Name	County	Platte	Thompson	Harrietta	Wolf Lake	Oden	Marquette
Partridge Pt., Lake Huron	Alpena	0	100,000	0	0	0	0
Rifle River	Arenac	0	0	3,100	0	0	0
Whitney Drain	Arenac	0	0	5,000	0	0	0
Alice Lake	Baraga	0	2,250	0	0	0	0
Cedar Lake	Barry	0	0	0	1,000	0	0
Lake Charlevoix	Charlevoix	0	0	5,075	0	4,925	0
Manistee River	Kalkaska	0	0	500	0	0	0
Higgins Lake	Roscommon	0	26,900	0	0	0	0
Coldwater River	Kent	0	0	0	10,000	0	0
Kearsley Creek	Genessee	0	0	0	580	0	0

Table 2. Examples of load and trip assignments from program DISPATCH for spring of 1983. These were truck trips to deliver yearling brown trout (BNT Y), rainbow trout (RBT Y), and Michigan-strain splake (SPM Y) from Thompson Hatchery.

	Destination			Load definition		
Trip number	Name	County	Town, range, section	Species name	Number by species	Weight by species (kgs)
Semi-truck trips						
1	Thunder Bay	Alpena	30N,8E,11	BNT Y	34,000	2,000
2	Thunder Bay	Alpena	30N,8E,11	BNT Y	32,000	1,882
3	Presque Isle Harbor	Marquette	48N,25W,2	BNT Y	15,000	882
4	Higgins Lake	Roscommon	24N,4W,10	SPM Y	25,000	1,471
Peterson truck trips						
1	Escanaba River	Delta	41N,23W,8	BNT Y	8,400	494
2	Escanaba River	Delta	41N,24W,2	BNT Y	10,400	612
3	Kunze Lake	Houghton	47N,35W,29	RBT Y	1,000	59
	Michigamme River	Marquette	46N,30W,18	RBT Y	1,500	88
	Paint River	Iron	44N,35W,9	BNT Y	3,380	199
	Paint River	Iron	44N,35W,1	BNT Y	3,380	199
	Paint River	Iron	44N,34W,11	BNT Y	3,380	199
4	Louise Lake	Charlevoix	32N,4W,11	SPM Y	10,000	588
	Maple River	Emmet	36N,4W,24	BNT Y	2,500	147
Manchester truck trips						
1	Railroad Lake	Dickinson	44N,30W,22	BNT Y	2,200	129
	Escanaba River	Marquette	44N,25W,21	RBT Y	2,275	134
2	Indian River	Schoolcraft	44N,18W,21	BNT Y	1,080	64
	Indian River	Schoolcraft	44N,18W,22	BNT Y	1,080	64
	Indian River	Schoolcraft	44N,18W,25	BNT Y	1,080	64
	Indian River	Schoolcraft	44N,17W,28	BNT Y	580	34
	Indian River	Schoolcraft	44N,17W,29	BNT Y	580	34
	Indian River	Schoolcraft	44N,17W,34	BNT Y	1,080	64
3	Beatons Lake	Gogebic	45N,40W,1	SPM Y	6,800	400
4	Brocky Lake	Marquette	48N,28W,6	RBT Y	5,250	309

Table 3. Distances driven (kilometers) and costs (dollars) of the actual planting of fish in the Great Lakes in 1979 versus distances and costs of the two computer-generated scenarious described in the text.

	Actual		Scenario 1		Scenario 2	
Truck type	Distance driven	Cost	Distance driven	Cost	Distance driven	Cost
Semi	19,854	2,780	21,854	3,060	19,490	2,729
Intermediate[1]	27,760	3,054	15,480	1,703	12,228	1,345
Manchester	12,238	1,101	6,346	571	4,560	410
Total	59,852	6,935	43,680	5,334	36,278	4,484

[1] Intermediate trucks had a similar loading capacity as the Peterson trucks mentioned in the text. Intermediate trucks were phased out of the fleet beginning in 1980.

LITERATURE CITED

Crecine, J. P. 1986. The next generation of personal computers. Science 231: 935–943.

Hiller, F. S. and G. J. Lieberman. 1974. Operations research. Holden-Day, Inc., San Francisco, USA.

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