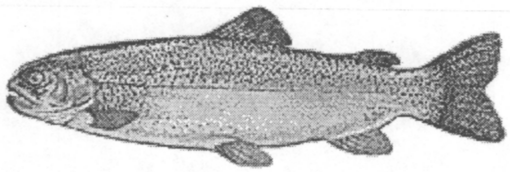
# A Model to Determine Success of Juvenile Steelhead



A Capstone Project
Presented to the Faculty of Earth Systems Science and Policy
in the
Center for Science, Technology and Information Resources
at
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in Partial Fulfillment of the degree of
Bachelor of Science

By
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4/20/01

Cover letter

Dear ESSP Reader,

The primary goal of my capstone is to determine the success of juvenile steelhead (*Oncorhynchus mykis*s) going out to the ocean using a computer model that I built. The model is based on the number of steelhead being born in the Arroyo Seco River and the effect of suspended sediment on juvenile steelhead as they move throughout the Salinas River to the Salinas River Lagoon. The Salinas River Lagoon is the smoltifications grounds for the steelhead, (smoltification is process that the steelhead go through to become acclimated to the salinity of the ocean). The lagoon was also in my model because the suspended sediment and temperature both affect the steelhead. Suspended sediment in small concentration, (under 20mg/l) does not physical kill the steelhead but it impacts the forage rate which impacts the survival rate of the steelhead as it reaches the ocean.

Steelhead are a very important natural resource just for the intrinsic value. I was raised fishing and steelhead was one of the fish that we used to go fishing for. I no longer go fishing for steelhead but I want the steelhead to be preserved for the future generations to be able to experience them in the wild. I was biased coming in to this project and my model is biased because of it. I focused only on sediment within the Salinas River and temperature and sediment in the Salinas River Lagoon as agents causing harm to the steelhead.

The significance of such an undertaking is, as a preliminary identifier of possible harm to steelhead on their way to the ocean. Interest in my model could come from people trying to assess the success of a project to reduce the concentration of suspended sediment in the Salinas River. Another possible use for my model is to hind-cast, if the concentration of sediment in the Salinas River is known for a given year then you can find out how many steelhead could have gone to the ocean.

For the Capstone assessment the areas of depth I am choosing are application of knowledge in the life sciences, and acquisition, display, and analysis of quantitative data. I have proposed the question, as well as, made a model to reach an answer. For the model I had to get data, such as a number of steelhead per meter that are capable of being in the Arroyo Seco. The model also gives a population estimate of steelhead and how much the sediment is affecting the steelhead. I combined the information form my own model and the literature review and put that information into a paper.

Roy Foster
4/20/2001

## Abstract:

The Salinas River system is important for both humans and wildlife. The Salinas River runs through a major multibillion-dollar agricultural area that the Salinas River waters are used to irrigate. It is also the home of Steelhead trout (*Oncorhynchus mykiss*), an anadromous fish that has been placed on the Endangered Species list. Placement on the Endangered Species list protects the steelhead from any person "harming" them. A model was made to determine how much "harm" is happening to the steelhead. The Arroyo Seco were used as the rearing grounds for the model because it is on of the last sizable rearing grounds in Salinas River watershed. David Dettman's method for steelhead habitat assessment was used to estimate the total number of fish that could be supported by the Arroyo Seco. Based on 1979 suspended sediment data the Salinas River could not support a healthy run of steelhead. The model calculated a reduction in feeding and a zero to twenty-percent mortality for the steelhead in 1979. The reduction in the feeding rate is important to understand that the size is directly related to how it survives in the ocean. It is also important to understand where the harm is coming from to protect the steelhead.

## Introduction:

The Salinas River within the Salinas Valley Watershed is a very important river. The Salinas River Valley Watershed recharges the aquifer that the people of the Salinas Valley pump to use for personal use and to irrigate a multibillion-dollar agricultural industry. The agricultural industry is by far the dominant industry in the valley. This has changed the very look of the valley, as flat cultivated lands take up most of the space within the Salinas Valley. In the Salinas River watershed, the Nacimiento and San Antonio Rivers have dams to catch and hold water for use. These practices have an impact on the wildlife, historically these rivers have had large runs of steelhead, *Oncorhynchus mykiss* (Franklin, 1999). Once dams were placed on these rivers the runs of steelhead quickly died out (Hagar, 1996).

Steelhead trout are anadromous salmonids that use the Salinas River watershed for their spawning grounds. An anadromous salmonid is born in a freshwater stream, and matures to an adult as it goes in to the open ocean where is spends its adult life foraging. It then returns to the stream where it was born to spawn. Steelhead usually only spawn once in their life but are capable of spawning multiple times (Trush, 1990). This ability is unlike most of the salmonid species, that die after spawning once (Lufkin, 1991).

The steelhead is an important species to look at because it is called an indicator species. An indicator species is one that researchers look to determine if the habitat that the species inhabits is healthy (Lufkin, 1991; Trush, 1990). Steelhead migrate over many thousands of miles, through the ocean and back to the same stream they were born. As they migrate any change within any of those systems can place additional hardships on the steelhead. With their lives in this precarious balance it does not take much to adversely impact the steelhead.

Within the Salinas River, there is virtually no spawning habitat left due to it being a low gradient sand bed stream with agriculture on both sides of the river (Hagar, 1996). The Nacimento and San Antonio Rivers, tributaries to the Salinas River, have had historical runs in the past (Franklin, 1999) but with the addition of the reservoirs on the rivers, those runs have all but stopped (Hagar, 1996). The Arroyo Seco, another tributary to the Salinas River, is the most pristine of the tributaries with current steelhead runs (Hagar, 1996; Franklin, 1999). The Arroyo Seco has agricultural fields, grazing pastures, and a gravel mine, creating disturbance along its lower reaches, within the river. The Salinas River, however, is the "highway" for the adult steelhead to get from the ocean to the spawning grounds and for the juvenile steelhead to reach the ocean.

The suspended sediment that moves down river is described in two different ways, as an acute sediment load and a chronic sediment load (Kochel, et al, 1995). A chronic sediment load refers to a constant load of sediment over a long period of time. Chronic sediment is caused by some human or natural disturbance up stream. If a stream bed is not at the correct angle for the stream, it will cut into the bed and remove sediment in one area and deposit it in another area to correct this (Kochel, et al, 1995). Another possibility that could contribute sediment in to the river is the agricultural field runoff. On the agricultural fields there are spaces of bare soil in between the crops. When water accumulates in these areas it can runoff the agricultural land taking sediment with it. If the riparian zone is not large enough the runoff can go in to the stream along with most of the sediment from the agricultural fields.

The other way suspended sediment moves within rivers is described as acute sediment load. Acute sediment load refers to when sediment moves in surges or plumes down the river over a period just a few hours, days, or weeks. Acute sediment can be caused by a storm that passes over and the rain surge moves a large amount of sediment down the river. Inman, & Jenkins (1999) define acute sediment load as the mean annual streamflow during the wet period [raining season], summed for all rivers [all small California rivers], exceeds that during the dry season by a factor of about three. In the raining season you have more sediment moving down the stream than during the dry season. Some of which will become a part of the bed load but some of the sediment will stay suspended in the matrix of the water column.

Sediment has a direct effect on steelhead as they emerge from redds (steelhead nest). The juveniles can not leave the redds due to entrapment by the sediment (Bratovich & Kelley, 1988). The sediment fills in the spaces between the rocks within the redds, where the embryos are developing. When they are ready to emerge from the redds, there is not enough space for them to escape and they eventually suffocate and die. Agricultural runoff and grazing have a potential to cause extra sediment that could entrap the fry as they try to emerge.

Sediment also negatively affects the juvenile steelhead by inhibiting their foraging ability, modifying their natural habitat, and acting directly on the upon the steelhead by potentially increasing in morbidity, alarm reaction times, and reducing resistance to illness (Newcombe, 1997). Sediment also negatively affects the juvenile steelhead as they move down the river before they enter in the ocean. At this stage in their development the steelhead are not large, ranging between 30mm to 35mm in length (Bratovich & Kelley, 1988). The juvenile steelhead need to forage on the way to the ocean to become big enough to survive in the ocean (Dobush et. al., 1992; Hankin & Nicholas, 1989).

Before the juvenile steelhead move out to the ocean, they go through a process called smoltification, typically in coastal estuaries, which are brackish. This is the time that the steelhead become adjusted to the high salinity of the ocean and grow large enough to survive out in the ocean by foraging within an estuary. Sediment can impact them at this stage as well, by having similar impacts such as decreased foraging rate and alarm reaction slowness. This time in the estuary is the last chance to gain mass before moving on the ocean, gaining mass improves the survival of the steelhead out in the ocean (Dobush et. al, 1992; Hankin & Nicholas, 1989).

There are many laws that protect anadromous fish (steelhead and salmon). Since 1991, steelhead and salmon have had 157,000 miles of stream protected under the Endangered Species Act, which is almost twice the area protected by the spotted owl (Brinckman, 1999). Steelhead have been placed on the Endangered Species list to protect the steelhead from a "person" to "take", which includes "harm" (Ellis, 1996). "Harm " is defined as an act that kills or injures the steelhead, and includes the modification of the habitat so that it impairs the behavioral patterns of the steelhead (Ellis, 1996). The Salmon, Steelhead Trout, and Anadromous Fisheries Program Act (Senate Bill 2261) is a Californian State Act passed to protect anadromous fisheries. The long-term goal was to double the populations of anadromous fish from 1988 to 2000 (NMFS, 1996). Projects include, water temperature control devices on dams, correcting fish passage problems, and adding riparian borders along rivers (NMFS, 1996).

There are other programs that are in place to help bring back the populations of anadromous fish, but most of the projects in place are not the correct approach. Projects need to focus on the entire river system not focus primarily on the steelhead (Trush & McBian, 2000). If the entire river system is restored the steelhead will recover on their own. To restore a river system the natural geomorphic processes need to have balanced sediment budget and a dynamic riparian plant communities (Trush & McBian, 2000). The river does not need to have unregulated flow nor does it need the same morphology as the pre-impacted river, the river just needs to function in a similar manor. To function similarly the river needs to be able to carry the contemporary sediment supply along with the contemporary flow regime (Trush & McBian, 2000).

Having a dynamic plan to restore the river is essential for having the steelhead populations recover, such as having a "grassroots" plan. A "grassroots" plan is a restoration plan that has people who live within that area with control over the recovery of steelhead populations. Without enforcement from an agency, the plan will be more successful as the landowners can take pride in the recovery. That same agency can then transform from being an enforcer to an informative role in that situation. Such a dynamic plan would be hard to start but would perpetuate itself. So far having enforcement agencies has not brought back the steelhead in our streams I think it is time for this new approach.

To understand what is effecting the fish a model could be very helpful. Crowder and Marschall produced a model to determine the effects of introduced species, siltation and acidity on Brook Trout in southern Appalachian mountain streams. Siltation and acidity have increased because of heavy logging in the headwaters of the Appalachian streams and fisherman introduced Rainbow Trout for fishing (Crowder and Marschall, 1996). It was found that the probability of survival was more sensitive to change than the population size (Crowder and Marschall, 1996). Crowder and Marshall found that their model was not good at predicting the population of Brook Trout, but it did work well for assessing the impact on the Brook Trout.

The goal of my project is to develop the outline of a model to determine if sediment is effecting the juvenile steelhead on their way from the rearing grounds in the Arroyo Seco, through the Salinas River "highway", and into the Salinas River Lagoon. I am focusing on the juvenile steelhead because once the steelhead reach the ocean there are many pieces to the steelheads life that is not known. I am also focusing on the Arroyo Seco River, because this is one of the last high-quality spawning habitats that remain for the steelhead in the Salinas River watershed (Hagar, 1996).

## Methods:

### Model:

I divided up my model (written in ANSI C) into three sections, one for the Arroyo Seco River, one for the Salinas River from the confluence of the Arroyo Seco down stream, and one for the Salinas River lagoon.

The model assumes that the steelhead move down the Salinas River within one year of leaving the redds. In reality some juveniles stay in the rearing grounds for up to four years (Trush, 1990). The Second assumption the model makes it that the steelhead swim to the smoltification grounds with out stopping. I consider the Salinas River to be a "highway" to the ocean for the steelhead. Although steelhead forage while swiming down the Salinas River on their way to the smoltification grounds, they do not stop for any significant amount of time because there is no protective cover is available in large concentrations for the steelhead (Hagar, 1996).

The Arroyo Seco River section is the rearing area for the steelhead. To find the total number of steelhead in the stream, the total possible number of steelhead to be held by the river is inputted into the model. The emergence survival rate of .582 (Bratovich & Kelley, 1988) is multiplied by the total possible number of steelhead to get an output of total number of steelhead to emerge.

I programmed the model to prompt the user to enter a suspended sediment concentration in milligrams per liter and length of exposure to the suspended sediment in hours. Then model will calculate an index number and the total number of steelhead in the Salinas River. To calculate the total number of fish in the Salinas River, the total number of steelhead to emerge is multiplied by a juvenile steelhead death rate of .25 (Crowder and Marschall, 1996) that is modified by the user inputted sediment concentration. Newcombe's equation:

Harm Index = 1.0642 + (0.6068*log(sediment mg/l)) + (.7384*log(exposure length))

is used to calculate the harm index. I programmed the model so that once the harm index is calculated the output will appear on the screen as a harm index number and the associated effect (table 1).

The Salinas River Lagoon section of the model is similar to the Salinas River section. The population size is determined by the first population of steelhead that have emerged on the Arroyo Seco multiplied the death rate and modifier used for the Salinas River that is modified by another user inputted sediment concentration. With the new sediment concentration and a new user inputted length of exposure Newcombe's equation was used to get an output of another harm index number and associated effect.

In the lagoon it is important that the steelhead grow to an optimal size to survive out in the ocean (Dobush et. al., 1992; Hankin & Nicholas, 1989) and temperature is a regulating factor in how much steelhead forage (Bratovich & Kelley, 1988). I have the model use the equation, [percent reduction = (0.5*temperature)-3], that incorporates the temperature of the lagoon to calculate a percent reduction in foraging rate. Lastly I use the lagoons' harm index to add on a second modifier to the death rate to give you the total number of steelhead that go out to the ocean. The model outputs

**Table 1**: Harm index number and associated description.

| Harm Index | Discription of Harm |
|---|---|
| 0 | No effects |
| 1 | alarm reaction |
| 2 | Abandonment of cover |
| 3 | Avoidance response |
| 4 | Short-term reduciton in feeding rates, and short-term reduction in feeding Success |
| 5 | Minor physiolgical stress, increase in rate of coughing and increased respiration |
| 6 | Moderate physiolgical stress |
| 7 | degradation and impaired homing |
| 8 | Indications of major physiological stress, long-term reduction in feeding rate, ong-term reduction in feeding success, and poor condition |
| 9 | Reduced growth rate and reduced fish density |
| 10 | 0 percent - 20 percent mortality and increased predation, moderate to severe habitat egradation |
| 11 | 20 percent - 40 percent mortality |
| 12 | 40 percent - 60 percent mortality |
| 13 | 60 percent - 80 percent mortality |
| 14 | 80 percent - 100 percent mortality |
| 15 | 100 percent mortality |

three different descriptors that help you decide if the steelhead had optimal foraging conditions and if they will survive out at the ocean.

**Parameterizing the Model:**

To determine the total number of possible steelhead on the Arroyo Seco I used the Dettman model (2000). The Dettman model (2000) uses the parameters: average depth, length, width, and velocity of the river, and the average cobble embededness, percent cover of vegetation, percent cobble, and roughness. These parameters need to be measured for each of the stream structures such as; pool, riffle, glide, or run. Each reach has many of these structures (Dettman. 2000). To find each of these, during the week of the 18$^{th}$ of March Brian Londquist and I, measured each of these parameters for two reaches of the Arroyo Seco. Each of the reaches is roughly 700 meters long and are representative of upper Arroyo Seco and lower Arroyo Seco.

The parameters were measured in the following manner. For the average depth, five random depths were taken with a two-meter measuring pole, then averaged together. The length and width were taken with a 100 meter transect tape. Cobble embededness was determined by taking the average of five haphazardly selected cobbles from the stream and looking at the sediment line. This is to determine how much the cobbles were covered with sediment. Percent cover of vegetation is an index between zero and two, zero being no vegetation or boulders along the banks and two being a complete canopy over the stream. Percent cobble is an estimate of what percent of the stream's structures bottom is covered with cobble substrate. Lastly, roughness is a descriptor of the texture of the bottom of the structure of the stream. Sand bottom being low roughness, boulders being high roughness, this is based on personal observation.

The stream structures were identified as follows: a pool is defined as a deep part of the stream usually greater than 1 meter in depth where the water is slow to stagnant. A riffle is the part of the stream that has a high velocity, very turbulent flow, and lots of cobbles and boulders. A run is the area where the riffle slows down due to an increase of depth of the within the stream, it is not turbulent and has a semi laminar flow, occurs between a riffle and a pool. Lastly, a glide is where a pool decrease in depth, the velocity increases, and it becomes critical flow. A glide is located between a pool and a riffle.

The Dettman model (2000) has a computer program that was used to produce a steelhead per meter squared using all the data collected (Dettman, 2000; Londquist, 2001). The Dettman model (2000) uses the average depth to get a quality number (0-1)($Q_1$). The quality number is added to an index number (0-8) on a matrix table of velocity of the river, cobble abundance and embededness giving you an new quality number ($Q_2$) (Dettman, 2000; Londquist, 2001). Roughness, distance to riffle, and vegetative cover are used to come up with a final new quality number (NQ). NQ is multiplied by two conversion factors to change from feet to meters giving you steelhead per meter squared (Dettman, 2000; Londquist, 2001).

We were only able to do two reaches of the Arroyo Seco. So I used the two reaches as a sub-sample of the lower and upper reaches. I divided the river up into lower and upper reaches above Throne Road. The upper reach study site on the Arroyo Seco River was located down stream of the entrance to the National Park. The Bridge at the kiosk was the end point for the study site and a road crossing down stream indicates the beginning of the study site. The river is lined along the northwest bank with homes, where the southeasterly bank is very steep with some vegetative cover. The river in this area has a pool-glide-riffle-run pattern. The lower reach study site was located down stream of the Green Bridge (road) crossing. The Green Bridge was the upper endpoint; the start point of the study was a large bend in the river that was almost a 90° turn to the northwest. The river is confined with in two cliffs with grazing and agricultural land on both sides. A few small trees were the only cover along the banks.

I went to the US Geological Survey web site to find suspended sediment data and try to get the suspended sediment data closest to the year 2000. The station I got he information from was USGS gauging stations on the Salinas River near Spreckles (station number 11152500). The database has 137 years of data for it but the latest suspended data information I could get was for 1979.

**Model Experiments and Sensitivity Analyses:**

Three experiments were carried out to do sensitivity analyses on the model. The first experiment was to see if a small change in the amount of sediment would have a large change in the index or the population size. To accomplish this I set the inputs of possible number of steelhead, Salinas River exposure time, and Salinas River Lagoon exposure time, are static.

The next experiment was to look at the population size to determine if a change in the initial possible population will have an effect on the population going out to the ocean. The inputs of sediment concentration, and exposure time were static. The increments of the population were, 100%, 75%, 50%, 25%, 5%, and 1% of the total possible population.

The last experiment was a sensitivity analysis on the exposure time. The inputs of total possible number of steelhead and sediment concentration were static, while the time intervals were changed. The Salinas River, intervals ranged from 24 hours to one week, were the Salinas River Lagoon intervals ranged from 2 weeks to 2 months.

## Results:

### Field Data:

On the Arroyo Seco River I used an upper reach and a lower reach for the two study sites. The upper reach study site on the Arroyo Seco River, was 428 meters long with an average width of 10 meters. The lower reach study site was located down stream of the Green Bridge crossing. The length of the lower reach was 858 meters long, with an average of 18 meters wide.

Brian Londquist used the Dettman model (2000) to determine the steelhead per meter squared. Lower reach has 15 steelhead per meter squared and the upper reach has 14 steelhead per meter squared (Londquist, 2001). The total length of the Arroyo Seco is 66 kilometers (CARA, 1997) and the two sets of reaches are 26.5 kilometers long. I multiplied the area of the set of reaches by the amount of steelhead per meter squared and add the two sets of reaches together to get a total number of fish possible of 10,865,000 steelhead.

From the USGS data for 1979, the mean annual suspended sediment was 363 mg/l. For hours of exposure to the sediment, I used 168 hours for length exposure in the Salinas River, which is roughly one week and for the length of exposure in the Salinas River Lagoon I used 1,440 hours, which is roughly 2 months.

### Model Experiments and Sensitivity Analysis:

For the sensitivity test on the change in sediment concentrations I keep all the parameters but suspended sediment concentration, static. For suspended sediment concentration I started with a concentration of .001mg/l, the sediment has no effect on the steelhead and with total number of fish possible of 10,865,000 steelhead, 4,742,572 made it to the ocean (Figure 1). The largest concentration of sediment I inputted in to the model was 1,000 mg/l of suspended sediment, and from total number of fish possible of 10,865,000 steelhead, 4,713,434 steelhead move to the Salinas River Lagoon. From that 4,713,434 steelhead only 4,684,296 steelhead made it to the ocean (Figure 1). Of the 4,684,296 steelhead to make it to the ocean harm indices were calculated, a harm index of 8 occurred in the Salinas River and a harm index of 10 occurred in the lagoon (table 1).

For test on the change in population, I took the 100 %, 75%, 50%, 25%, 5%, and

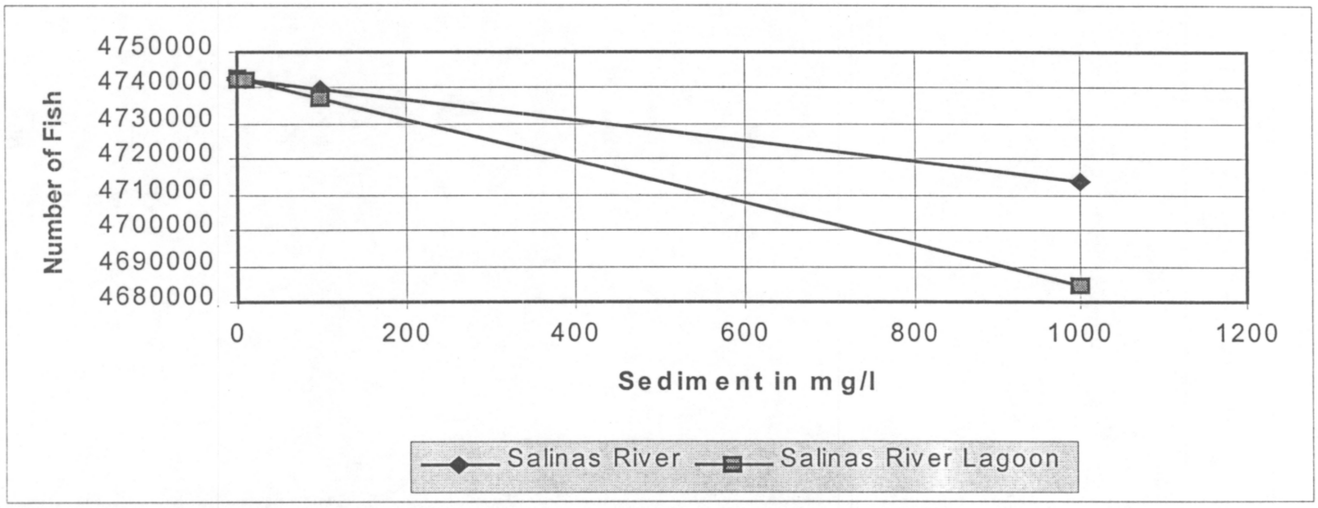


Figure 1: Graph of number of steelhead plotted against amount of sediment

1% of the total possible number of steelhead. Then I kept the amount of sediment for each static at the 1979 mean annual suspended sediment concentration. For 100% of the total possible number of fish, the amount going to the ocean is 4,721,418. For 1% of the total possible number of fish, 47,213 steelhead make it to the ocean (Figure 2).

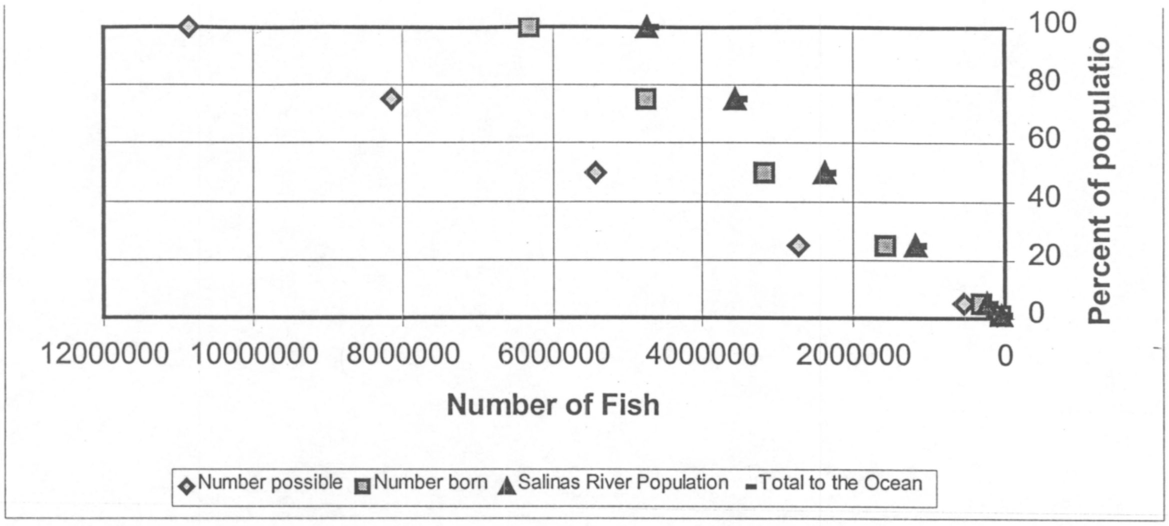


**Figure 2**: Graph of Percent of the population plotted against Number of fish

The final experiment performed was a sensitivity analysis on the amount of time the steelhead remain in the concentration of suspended sediment. I kept the amount of sediment for each static at the 1979 mean annual suspended sediment concentration. I then changed the exposure length to the suspended sediment in the Salinas River from 24 hours to 168 hours, and in the Salinas River Lagoon from 432 hours to 1440 Hours. In the Salinas River, at the mean 1997 suspended sediment concentration for 24 hours, the model calculated a harm index of 6 (Table 1, Figure 3). In the Salinas River lagoon for 1440 hours, the model calculated a harm index of 9 (Table 1).

## Discussion:

### Field data:

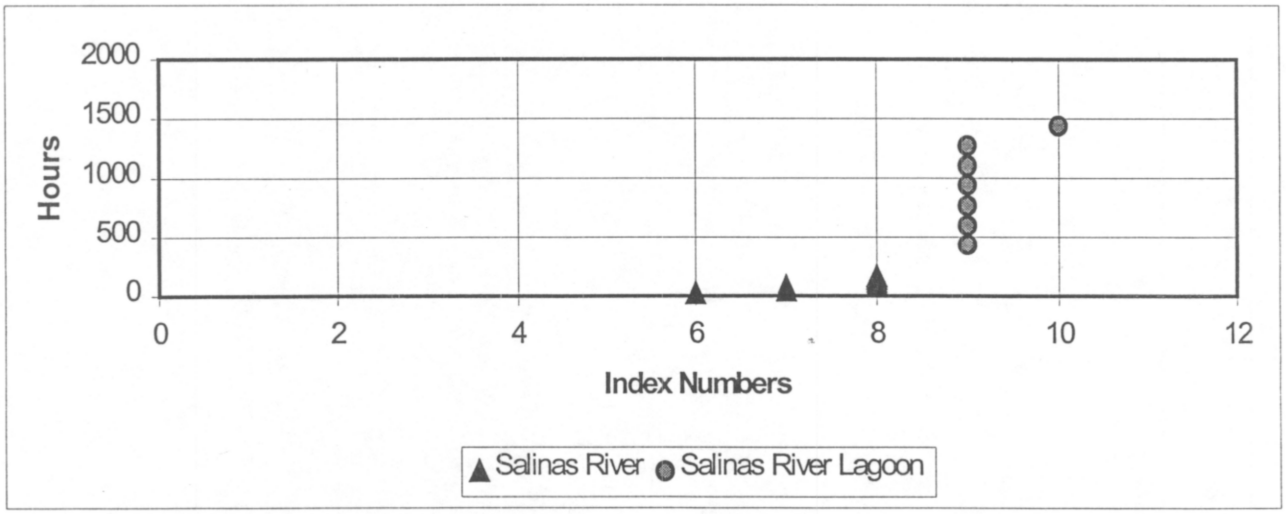


**Figure 3:** Graph of hours of exposure to a concentration of 363 mg/l by the Harm Index

From Dettman's model (2000) I got a number of steelhead per meter squared and I multiplied it by the area of the Arroyo Seco to get the number of steelhead for the Arroyo Seco River above Throne Road. The number of total possible steelhead was 10,865,000 steelhead. The Dettman model was changed from US standard units to metric units creating a .03 calculated error (Londquist, 2001) which could skew the number of total possible steelhead. 10,865,000 sounds a little big but I have nothing to compare it to so I can not be sure at how accurate the Dettman model (2000) is.

The suspended sediment data that I used in my model was 1979 annual average of 363 mg/l. 1979 was a wet year at the end of a drought, some of the suspended sediment peeks were greater than 4000 mg/l and as low as 10mg/l. This could be caused during the drought years not much sediment was transported and then when the drought was over the river needed to move more sediment creating the peeks. What also happens is that during a drought the vegetation on the banks die off so that when the high flows come back through the river there is nothing to hold the banks in place contributing to excessive sediment in the river.

**Model Experiments:**

For the first experiment, I changed the amount of sediment in the Salinas River and Salinas River Lagoon. At lower concentrations the suspended sediment dose not have much of an effect on the steelhead. For a sediment concentration of .001mg/l, the Salinas River population was 4,742,572 and the same population made it out to the ocean. When I increased the sediment concentration to 1000mg/l there was a large drop in numbers from the Salinas River to the ocean, of 29,138 steelhead. Between the two that is a large loss of steelhead.

For the next experiment, I changed the total number of possible steelhead to be on the river. I took a percentage of the total number possible to look at the ocean going populations. Graph 2 shows a linear relationship between the percentage and the population size, which is what I expected of the model. The less steelhead you have initially the less steelhead you will have in the end and all the populations where subject to the same concentration of sediment and exposure interval.

For the last experiment, I changed the exposure interval of the steelhead to the suspended sediment. Graph 3 shows an exponential curve when exposure time it plotted against harm index number. I expected to see this trend, as sediment effects the steelhead in the beginning it takes smaller intervals of sediment concentrations to harm the steelhead but it takes larger amount to compound the effects of the smaller concentrations.

I put temperature in as a component for the lagoon section of the model. I did not test for the effects of temperature because it has a linear relationship to the foraging rate (Bratovich & Kelley, 1988). Under sixty degrees Fahrenheit the temperature has no effect on steelhead forage rate (Bratovich & Kelley, 1988). From sixty to eighty degrees Fahrenheit it is a linear relationship where sixty degrees Fahrenheit is no effect to eighty degrees Fahrenheit which the forage rate falls to zero (Bratovich & Kelley, 1988).

## Conclusion:

The model showed that in the year of 1979, the Salinas River could not hold a healthy steelhead run. Natural process could be the reason for the high amount of suspended sediment with in the river; they have a strong effect on the fluvial morphology

(Inman & Jenkins, 1999). I looked at the hydrograph for this year and it has a discharge of a little higher than the mean for the years subsequent to 1979.

The Salinas River is a sand bed river with exposed banks in an agricultural valley (Hagar, 1996). If there is higher discharge during a year with no vegetation on the banks of the river, there is nothing to stop the mobilization of those banks from creating suspended sediment. Agricultural fields along the banks contribute to agricultural runoff into the Salinas River, which can carry more than just sediment. A riparian barrier along the banks of the Salinas River will help, by reducing the sediment from being mobilized and harming the steelhead. This barrier of riparian vegetation will increases bank stability, soil alteration, and reduce both temperature and sediment in the stream (Adam, et. al, 2000).

The model can be a stepping stone in trying to assess the harm that the sediment is doing to the steelhead. I have identified "Harm" as an act that kills or injure the steelhead, also including modification of the habitat so that it impairs the behavioral patterns of the steelhead (Ellis, 1996). Sediment in the Salinas River truly "harms" the steelhead and some protection is need for this endangered species.

**Future Direction:**

This model is just a beginning to understanding what is going on in the Arroyo Seco, Salinas River system. To make the model more robust, two suggestions are to use a death rate that was calculated on the Salinas River and have an exposure length component in the death rate modifier. Also to get a better idea of how the sediment is effecting the steelhead more that one years of suspended sediment data should be used to round off the unusually high sediment years. Having multiple sections where you can measure sediment for each and really narrow down where the sediment is effecting the steelhead.

This model was just a beginning in a long process, but it works at showing that sediment does effect steelhead. It is a beginning to understanding what is harming the steelhead and where. This model is a great point resource to find what information will be needed for more robust and compressive model.

## Acknowledgments:

Brian Londquist for the data on the Arroyo Seco which without, this model would not work. Thank you Mary Wackerman for your help with the data collection on the Arroyo Seco and a good laugh when it was needed. Dr. Robert Curry for suggesting this project and helping by being my advisor and pointing me in the correct direction. Dr. Lars Perice for help with the C programming and also by being my advisor. And lastly April Mcmillian for giving me the support I need while writing this report.

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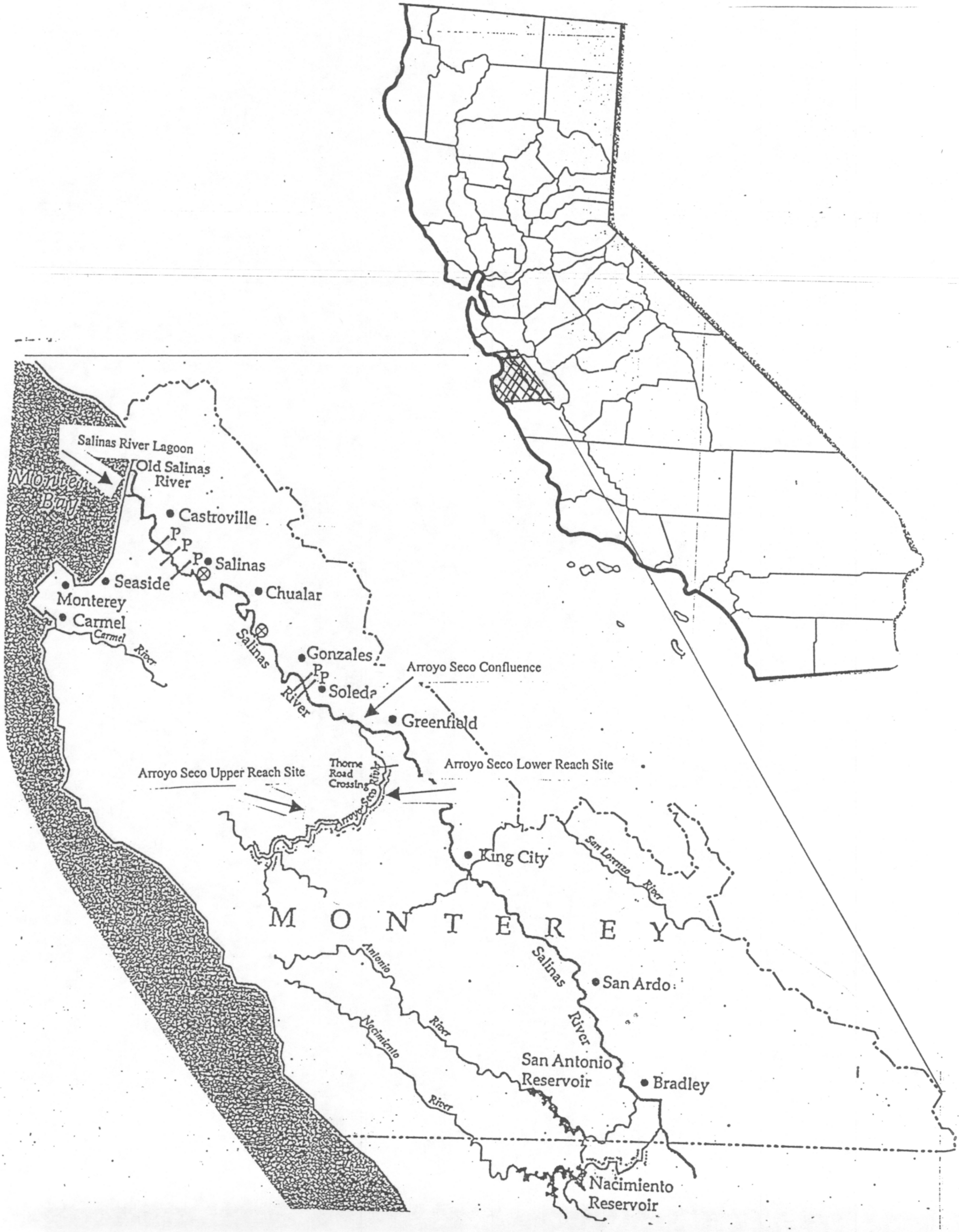
## Appendix:

A: Overall map of study region with labels of important areas.

B: The model code


Salinas River Lagoon
Old Salinas River
Monterey Bay
Castroville
Salinas
Seaside
Monterey
Carmel
Carmel River
Chualar
Salinas River
Gonzales
Soleda
Arroyo Seco Confluence
Greenfield
Thorne Road Crossing
Arroyo Seco Upper Reach Site
Arroyo Seco Lower Reach Site
Arroyo Seco River
King City
San Lorenzo River
MONTEREY
Antonio River
Nacimiento River
Salinas River
San Ardo
San Antonio Reservoir
Bradley
Nacimiento Reservoir

```
/*A model of the Salinas River, and Arroyo Seco for, effect of sediment on steelhead
* /
/*created
3/19/01-----------------------------------------------*/
/*by Roy Foster
------------------------------------------------------*/
/*--------------------------------------------------------------
* /
/*--------------------------------------------------------------
* /

#include <stdio.h>
#include <math.h>
main()
{

 /*declairation of variables*/
 float sediment, rearing, hours, death_r, death_mod;
 float death_r2, death_mod2, rear_surv, sediment2, hours2, forage;
 int impact, impact_2, num_fish, num_as, num_sr, temp;


/*-------------------Rearing  Grounds---------------------------------*/
 printf("------------Arroyo  Seco  rearing  grounds---------------\n");
 /*knowns*/
 rear_surv=.582;


 /*promt user for rearing index, or number of posable fry to be born*/
 printf("Type in total number of posable steelhead that can be born,  index:\n");

 /*reads in the number of rearing index*/
 scanf("%f", &rearing);

 /*equation*/
 num_as = rearing * rear_surv;

 /*print the number of steelhead fry to be born*/
 printf("The number of Steelhead to be born is: %d \n",num_as );
```

```
/*---------------------Salinas    River----------------------------------------*/
printf("-------------Salinas   River----------------\n");
/*knowns*/
death_r=.25;

/*promt user for amount of sediment in mg/l*/
printf("Enter the amount of suspended sediment in mg/l: \n");
scanf("%f", &sediment);

/*promt user for length of time of exposer in hours*/
printf("Enter the length of time the steel head are exposed to sediment in
hours:\n");
scanf("%f", &hours);

/*equation (Newcombe, 1997)*/
impact= 1.0642+(0.6068*logf(sediment))+(0.7384*logf(hours));

/*print out impact number*/
printf("The impact index number is: %d \n", impact);


/*print out harm index and discribtion (Newcombe, 1997)*/
if(impact >=15)
 printf("100  percent  mortality\n");
else if(impact==14)
 printf("80 percent - 100 percent mortality\n");
else if(impact==13)
 printf("60 percent - 80 percent mortality\n");
else if(impact==12)
 printf("40 percent - 60 percent mortality\n");
else if(impact==11)
 printf("20 percent - 40 percent mortality\n");
else if(impact==10)
 printf("0 percent - 20 percent mortality and increased predation, moderate to
severe habitat egradation\n");
else if(impact==9)
 printf("Reduced growth rate and reduced fish density\n");
else if(impact==8)
 printf("Indications of major physiological stress, long-term reduction in feeding
rate, ong-term reduction in feeding success, and poor condition\n");
else if(impact==7)
 printf("Moderate habitat degradation and impaired homing\n");
```

```
else if(impact==6)
 printf("Moderate physiolgical stress\n");
else if(impact==5)
 printf("Minor physiolgical stress, increase in rate of coughing and increased
respiration\n");
else if(impact==4)
 printf("Short-term reduciton in feeding rates, and short-term reduction in feeding
Success\n");
else if(impact==3)
 printf("Avoidance response\n");
else if(impact==2)
 printf("Abandonment of cover\n");
else if(impact==1)
 printf("alarm reaction\n");
else
 printf("No effects\n");

 /*equations for total population of steelhead*/
 death_mod=.000004608*sediment;

 num_sr= num_as - ((death_mod+death_r)*num_as) ;

 /*print out the number of fish that are in the Salians River*/
 printf("Number of fish in the Salinas River: %d \n", num_sr);

/*---------------------estuary--------------------------------------*/
printf("-------------Salinas River Lagoon---------------\n");
/*knowns*/
 death_r2=.25;

 /*promt user for amount of sediment in mg/l*/
 printf("Enter the amount of suspended sediment in mg/l: \n");
 scanf("%f", &sediment2);

 /*promt user for length of time of exposer in hours*/
 printf("Enter the length of time the steelhead are exposed to sediment in hours:\n");
 scanf("%f", &hours2);

 /*equation (Newcombe, 1997)*/
 impact_2= 1.0642+(0.6068*logf(sediment2))+(0.7384*log(hours2));

 /*print out impact number*/
```

```
printf("The impact index number is: %d \n", impact_2);


/*print out harm index and discribtion (Newcombe, 1997)*/
if(impact_2 >=15)
 printf("100 percent mortality\n");
else if(impact_2==14)
 printf("80 percent - 100 percent mortality\n");
else if(impact_2==13)
 printf("60 percent - 80 percent mortality\n");
else if(impact_2==12)
 printf("40 percent - 60 percent mortality\n");
else if(impact_2==11)
 printf("20 percent - 40 percent mortality\n");
else if(impact_2==10)
 printf("0 percent - 20 percent mortality and increased predation, moderate to
severe habitat degradation\n");
else if(impact_2==9)
 printf("Reduced growth rate and reduced fish density\n");
else if(impact_2==8)
 printf("Indications of major physiological stress, long-term reduction in feeding
rate, long-term reduction in feeding success, and poor condition\n");
else if(impact_2==7)
 printf("Moderate habitat degradation and impaired homing\n");
else if(impact_2==6)
 printf("Moderate physiolgical stress\n");
else if(impact_2==5)
 printf("Minor physiolgical stress, increase in rate of coughing and increased
respiration\n");
else if(impact_2==4)
 printf("Short-term reduciton in feeding rates, and short-term reduction in feeding
success\n");
else if(impact_2==3)
 printf("Avoidance response\n");
else if(impact_2==2)
 printf("Abandonment of cover\n");
else if(impact_2==1)
 printf("alarm reaction\n");
else
 printf("No effects\n");
```

```
/*temperature  equation*/
/*prompt for water temperature in the lagoon degrees f*/
printf("Type in the water temperature in degrees fahrenheit:\n");
scanf("%d", &temp);

forage=(.05*temp)-3;
/*print out temperature factors*/
printf("With a temperature of %d the percent of reduction of forageing of the
steelhead is %f  (if the number is greater than 1 then the steelhead stop eating, or if
the number is a negitive number then there is no efect on the forage rate of the
steelhead)\n", temp, forage);


/*equations for total population of steelhead*/
death_mod2 = .000004608*sediment2;

num_fish=num_as - ((death_mod2+death_mod+death_r2)*num_as);

/*print out the number of fish that are in the Salians River*/
printf("Total number of fish going out to the ocean: %d \n", num_fish);


/*------------------------------------------------------------------
*/
/*Referances:
-----------------------------------------------------*/
/*Newcombe, Charles P. Channel Suspended Sediment and Fisheries------------*/
/*:  A  Concise  Guide,  1997------------------------------------------*/
/*------------------------------------------------------------------
*/


}
```