# THE HYDROLGY of TISBURY GREAT POND

# MARTHA‟S VINEYARD, MASSACHUSETTS

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WEST TISBURY, MASSACHUSETTS

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# 1. INTRODUCTION

## a) Summary

Many people are concerned about the condition and use of Tisbury Great Pond. Using limited data, many studies have been carried out and many conclusions have been reached on the amount and source of water that enters The Pond. The author, is a riparian owner and interested geotechnical engineer, who has accumulated 40 years of measurements of ground water, surface water and rain water around the pond. This report is a compilation of those measurements, a presentation of hydro-geologic calculations and conclusions based on those measurements and calculations.

## b) Geography

Tisbury Great Pond is brackish pond of about 700 acres within the Towns of Chilmark and West Tisbury on the south coast of Martha‟s Vineyard Island about 5 miles off the southeast coast of Massachusetts. The pond lies within the glacial outwash plain formed by the post glacial erosion of the two major glacial moraines that form the island of Martha‟s Vineyard (Delaney). Many test borings made over the years show this plain to consist of a very permeable fine to coarse sand deposit about 100 feet thick overlying a very impermeable silt and clay strata several hundred feet thick overlying bedrock. The pond is separated from The Atlantic Ocean by a barrier beach of coarse sand several hundred feet wide formed by wind and wave action. Fresh water enters the pond by direct precipitation, two stream flows and ground water inflow. Salt water also enters the pond as ocean water pushed through the barrier beach by wave run up. A channel is excavated in the barrier beach about four times a year to allow the water that builds up in the pond to drain out into the ocean and to allow daily tidal flow to “flush” the pond with salt water.

## c) Responsible Political Bodies

The pond is owned by The State of Massachusetts as a “Great Pond” and is under the control of several State agencies. Activities on and around the pond are most directly regulated by Chilmark and West Tisbury‟s Conservation Commissions, Zoning Regulations, Boards of Health, and shell and fin fish agencies. The Martha‟s Vineyard Commission and The Martha‟s Vineyard Shellfish Group have tested and studied the pond over the years and have significant regulatory responsibility for the condition of the pond. In 1904, The Massachusetts State Legislature authorized “The Riparians Owner” to drain the lowlands surrounding the pond by excavating a channel through the barrier beach and draining the pond out to the ocean. In 1976, the Conservation Commissions of West Tisbury and Chilmark approved an “Order of Conditions” for the excavation of a channel through the barrier beach. “The Riparian Owners of Tisbury Great Pond” annually elect three Commissioners to drain the pond as needed. Tisbury Great Pond is now used extensively for fin and shell fishing, summer recreation, harvesting of salt hay along its shores and wild life habitat.

d) Previous Studies

Many studies and reports on Tisbury Great Pond have been published and an incomplete list is given in the appendix. The studies most pertinent to the hydrology of the pond are by Delaney 1980 of The US Geological Service (USGS), studies done from 1996 to the present by William Wilcox, Water Resource Planner for The Martha‟s Vineyard Commission and by Fugro-McClelland(East) 1992 prepared for the Towns of Chilmark and West Tisbury.

e) Acknowledgements

Many people have helped to gather data for this report, review maps and graphs and offer positive and negative comments. William M. Austin and the staff at Vineyard Land Surveying and Engineering, William M. Wilcox, Craig Saunders and K. Malcolm Jones and Judy Elmer, who edited the text, have helped the most.

f) Revisions

The first edition of this report was published in 2009. The major 2013 revisions are the 700 acre expansion, 5550 to 6250, of the assumed ground water shed based on two more ground water flow direction triads, measurements of water flow, in and out, through the barrier beach and calculation of the rain water recharge of the water shed ground water based on ground water measurements at the head of the water shed.

2. DESCRIPTION OF TISBURY GREAT POND

a) USGS Map

The best description of The Pond is provided by The US Geological Survey quadrangle maps of Squibnocket, Tisbury Great Pond, Vineyard Haven and Naushon Island. The appropriate portions of those four quadrangles have been pieced together to form Fig. 1. These maps show important geographical features and elevation contours with the National Geodetic Vertical Datum of 1929(NGVD) as the elevation datum. This “mean sea level” datum has been established on Martha‟s Vineyard on bronze plaques and other permanent benchmarks and is used by most agencies. In the area south of Tisbury Great Pond, the actual mean sea level of the Atlantic Ocean is about 1+ feet above this datum so that confusion sometimes occurs when discussing elevations. Figure 1, which will be referred to throughout this report, also shows the location of test borings that were made under the auspices of The Martha‟s Vineyard Commission and the author, the location of groundwater monitoring wells, groundwater contours that were derived from these wells, and watershed boundaries that were derived from map and field measurements. The 1929 NGVD elevation of the rim of the wells was determined by the author with conventional surveying equipment and the help of friends. At seven locations, there are three wells close together which allow the determination of the direction of ground water flow, shown by arrows in Fig. 1.

b) Test Borings

The logs of the test borings where samples were obtained or tested are given in Table 1.
The test borings MVC#4, MVC#5, MVC#6 and MVC#10 were done with rotary well drilling rigs

with split spoon samples retrieved every 10‘‘ or change of strata. These disturbed samples were identified and tested for permeability. Three piezometers made from ¾” rigid PVC flush joint tubing with one foot long screens at the lower end were placed in each test hole with the screens at the bottom of the sand strata, at the middle of the sand strata and at 5 feet below the groundwater table. These piezometers have been used to measure the elevation of the groundwater table, the slight vertical gradient that occurs during recharge and for sampling the groundwater.

The MVC Test borings #8 and #9 were done with a 6” diameter auger to about 10‘‘ below the groundwater table. Sand samples taken off the auger flights were identified and the permeability measured. A 2” diameter rigid PVC flush joint tubing with a 3‘‘ long screen was pushed down below the water table and used to monitor the groundwater table.
The ½” pipe probes were sections of ½” steel pipe with a 6” long section with eight 0.020” wide by 3” long longitudinal slots machined in it, with a plug at the end of the pipe. Water inflow through this slotted section was measured under a range of pressure differences to allow measurement of the permeability of sand that the probe was driven into. The pipe was driven with a 20 pound weight at two locations on the barrier beach to determine the depths of the barrier beach sand deposit, the pond bottom peat layer and the original sand and gravel glacial out wash deposit.
These test borings confirmed what previous borings had shown, that the outwash plain consists of fine to coarse sand about 100 feet thick sloping at about 100/20,000 southward from the center of the island, with the groundwater table sloping at about 20/12,000 to the ocean.

c) Stream and Dams

The two major streams, Tiasquam River and Mill Brook that flow into The Pond at Town Cove, originate in the glacial moraine upland area of West Tisbury and Chilmark. Chilmark Pond lies between the water shed of the Tiasquam River and Tisbury Great Pond, therefore the ground water from the Tiasquam watershed cannot enter Tisbury Great Pond. The outside edges of the watersheds of these streams were defined on Figure 1 by drawing lines between topographic highs. Where the streams enter West Tisbury, the definition of whether rainwater entered the pond by runoff into the streams or by percolating down through the sand strata and entering as ground water, was based on local water table elevations, recognizing that the actual ground water flow path depended on antecedent weather conditions and varied with the season and pond elevation. The stream flows were measured at the Mill Pond dam and the Douglas dam by calibrating the flow over the dam weirs to the pond water levels and measuring the pond levels continuously with “Stevens” float/paper chart, battery operated water level recorders. There were some interruptions resulting from mechanical failures or freezing but a good record of stream flows was obtained from 1993 to the present.
Tisbury Great Pond has been connected to Black Point Pond to the west by a “Crab Creek” channel about 20 feet wide and three feet deep, originally dug by hand but most recently re-excavated by machine in the sixties, to drain the lowlands around Black Point Pond and allow harvesting of salt hay (Whiting). This channel allows rain that enters Black Point Pond, directly or by ground water, and the ocean water that is pushed through in the barrier beach by wave run up, to flow into Tisbury Great Pond when it is low and allows brackish water to flow from The Pond when it is high out through the barrier beach on the south side of Black Point Pond.

d) Pond Depth

In 1992, Fugro-McClelland(East) measured the depth of The Pond as part of their study. The area of The Pond surface, as it varies with pond surface elevation from their report, is shown in Figure 2.

e) Barrier Beach

The barrier beach, about 200‟ wide and 8‟ to 15‟ above 0 NGVD, is coarse sand formed by the wind and waves across the southern side of the ponds that now exist along the south side of Martha‟s Vineyard Island. This beach has moved northward several miles as the island has eroded after formation of the outwash plain thousands of years ago. During the time since, sediments have formed in the deeper portions of The Pond, and consolidated into a 5‟ to 10„thick impermeable layer on the bottom. Chunks of this peat are periodically exposed on the ocean side of the beach. This peat layer was located in only two places by ½" pipe probes, but it is generally assumed to extend along the entire south side of Tisbury Great Pond and Black Point Pond.

f) Ocean Elevation

The elevation of The Atlantic Ocean controls the flow of pond water out through the barrier beach and out through the channel when open in the beach. Riparian owners have long known that the 1929 NGVD "mean sea level" elevation is about one foot below the actual mean sea level. Measurements of the actual sea level were made when there was little surf, by throwing the screened end of a 200‟ long ¼" diameter plastic tube out past breaking waves and comparing the elevation of the water over the screened end to a 1929 NGVD bench mark on the barrier beach, by measuring the vacuum needed to pull ocean water up to the bench mark. These measurements confirmed that as of 2013, actual mean sea level is 1.5‟ +- 0.1‟ above 1929 NGVD "mean sea level". The Martha‟s Vineyard Coastal Observation (MVCO) tower, installed in the year 2000 about one mile off Katama beach in Edgartown, continuously measures the elevation of the ocean surface at the tower using "mean sea level" as a datum. The vertical distance from that datum to the 1929 NGVD is not clear, but the measurements of ocean elevation off the pond are being compared with the MVCO ocean levels.

3. FIELD MEASUREMENTS

a) Ground Water Elevation and Flow Direction

The flow of rain water into and out of Tisbury Great Pond is controlled by gravity and the medium through which it flows. The elevation of all water surfaces must be known for any hydrologic study of The Pond. Many hours were spent with conventional surveying equipment to determine the elevation, to the nearest 0.02 feet, with respect to the numerous 1929 NGVD bench marks established around Martha‟s Vineyard by governmental surveys, and recorded on USGS maps and in reports. Many additional bench marks established by local surveys were made available to the author. The elevation of the water table in seven sets of three or more wells close together, shown in Figure 3a –3g, was determine periodically and the direction of ground water flow calculated graphically by assuming a plane water table surface between the wells and assuming ground water flow to be perpendicular to a water table contour. Both assumptions are reasonable in an homogeneous soil. These directions are shown on Figure 1. and allowed the drawing of the watershed boundaries within the outwash plain. The groundwater flow direction varies somewhat with the antecedent weather and, near The Pond, substantially with the level of The Pond.

b) Ground Water Table Elevation at Well #122

The elevation of the ground water table in well #122 at the Author‟s house has been recorded weekly since 1986 and the precipitation measured with three types of rain gauges, a plastic funnel type, a tipping bucket self emptying electrically recorded type and straight sided cans. Snow falls were collected to measure the equivalent rain. The rainfall measurements have been confirmed by other local gauges. Well #122 is at the head of watershed of the pond, and periodic measurement of the water table at well MVC #8 established that well #122 accurately reflected the water table within the water shed.

The elevation of the ground water table at well #122 and the bi-monthly precipitation from 1986 to the present are shown in Figure 4. The amount of rainfall from November 1, to May 1 for each year has been noted as related to the yearly recharge to the ground water. The dates were chosen arbitrarily, knowing that the exact amount varies with the weather conditions that year and the condition and location of the area. The yearly recharge is more nearly equal to the amount of rain from November 1 to May 1, minus the amount of rain that is retained during the wet season in the upper 4-6 feet of soil and is evapotranspired during the dry season.

c) Downward Percolation Rate

In 1987, the author bought a “Troxler” nuclear down hole soil water content measuring device and measured the rate that a heavy rainfall percolated down through fine to coarse sand underlying the site at well #122. Only one successful set of measurements over a period of about one month was made in December 1987 and January 1988. This set indicated that 5 inches of rain created a moisture front that descended through the sand at about ½ foot per day. Subsequent fees imposed by The U.S. Nuclear Regulatory Commission made disposal of the device imperative. The “Troxler” also measured the change from about 12 pounds of water per cubic foot during the wet season to about 3 pounds of water per cubic foot during the dry season in the upper 4-6 feet of soil. This amounts to about 7 inches of rain that is available for transpiration in addition the rainfall in the summer.

d) Stream Flows

In 1994, the water flow over the outlet weirs on the Mill Pond dam and the Douglas dam was measured with a propeller driven recorder at various pond elevations and water level recorders were then installed on both ponds to provide a continuous record of water flows from the streams into The Pond. The response of the streams to various rain falls has been analyzed and presented to the dam owners as part of Phase I Investigations that were done by the author for the dam owners as required by The Massachusetts Dam Safety Agency. The continuous record of stream flow allows the compilation of inflow to The Pond at any time since 1994. A typical response of Mill Brook flow to a rainfall is shown in Figure 5. Calculation of the runoff coefficient of about 0.07 shows the effect of the high percent of woodland, wetlands and ponds on the watershed. The flow soon after heavy rains is about 10% of the base flow. The 10 day average flow rates at The Mill Pond Dam and The Douglas Dam from 1994 to 2012 are given in the appendix and a summary of yearly flows from both streams is given in Figure 6.

e) Elevation of Tisbury Great Pond at Town Cove

The elevation of the pond surface at Town Cove has been measured with a battery powered "Belfort" float gauge with a paper recorder since 1993, and with a "Telog" battery powered pressure transducer with a chip recorder since 1996. Pond level have been recorded manually almost every week and more frequently during critical periods. The "Telog" records the water pressure to the nearest 0.01 feet of water over a fixed point every 15 minutes and when the recording chip is downloaded to a PC, the water pressure can be plotted versus time. This feature allows accurate measurement of rate of volume change of The Pond. In 1998 when The Pond was not open to the ocean and there was no wind, bench marks were placed at the southern end of The Pond and at Town Cove. The set up caused by a 15 to 20 MPH southwest wind was about 0.03 feet, so that the magnitude and direction of the wind was generally noted when pond levels were measured. A set up of 0.03 feet is enough to cause significant continuous return flow within the bottom several feet of the pond. This return flow cause bottom vegetation to visibly deflect and completely mixes the pond water in a few days. The elevation of the pond at Town Cove from 1993 to 2013 is shown in Fig. 7.

f) Beach Channel Flow

The elevation of The Atlantic Ocean along the south side of Tisbury Great Pond varies twice daily from about +0.5 to + 2.5 feet above the NGVD 1929 datum with greater extremes during "spring" (full and new moon) tides. The barrier beach between The Pond and The Ocean varies in width from 200 to 300 feet and in height from 8 to 15 feet above 1929 NGVD mean sea level. In 1904, The Riparian Owners were authorized by a Chapter 203 Massachusetts State Law to appoint three Commissioners to excavate a channel in the barrier beach between The Pond and The Ocean to "properly drain the lowlands and meadows around such great pond".

When the pond is about 5 feet above 1929 NGVD, a 10‟ wide by 3‟ deep channel is dug through the barrier beach in a few hours with a 100 horse power excavator allowing the water in the pond to flow out to the ocean at a peak rate of about 5000 ft3/second with a power of about 2000 horsepower eroding a channel in the beach 10‟ deep and 100‟ wide in about ten to fifteen hours (generally two tides). The channel is filled back in with sand by ocean wave and currents from 1 to 200 days after it is dug depending on the weather. With a wide and deep channel, The Pond rises and falls about one foot from about +1.5 to +2.5 above 0.0 NGVD twice a day. The rise and fall of The Pond after a "good" opening is shown in Figure 8. Several attempts were made to measure the outflow and inflow rates by walking a propeller velocity meter across the channel while measuring the water depth. The flow rate for a few hours could measured but measurement during several tide changes was not done because of seaweed clogging the meter, erosion changing the channel and lack of volunteers.

g) Flow Through The Barrier Beach

In 2012, four wells made of 4 inch diameter PVC pipe were installed open ended to about two feet below the water table in a line between the ocean and the pond, as shown in Fig. 1 and Fig.12. The elevation of the groundwater in wells #2 and #3 was continuously measured with battery powered "Telog" recorders, and intermittently by hand in wells #1 and #4. Samples of the barrier beach sand were taken from the well holes and the sides of channel cuts for permeability testing.

## 4. CALCULATIONS OF FLOW

a) Rise and Fall of Ground Water Table at Monitoring Well #122

The seasonal rise and fall of the groundwater table at well #122 at the head of the water shed, as shown in Figure 4, results from percolation of rain down through the outwash sand when the rain is not captured and held by the silty soil and the vegetation that has developed in the top 4-6 feet. Measurements with the "Troxler" meter indicated that the water in the upper 4-6 feet of silty soil increased from 3 pounds per cubic foot to 12 pounds per cubic foot after the start of the wet season. This increase represents about 7 inches of rain. In the late autumn (Nov. 1) most of the transpiration by the vegetation has stopped and the upper soil zone is resaturated by rain and excess rain begins to percolate down through the outwash sand. Many studies have indicated that on well drained sandy soil deposits in this part of southeastern Massachusetts, about 1 ½ feet of rain per year percolate down to the groundwater table. When the water reaches the groundwater table it no longer moves just downward but starts to flow laterally toward the nearest surface outlet, streams, estuaries, ponds or the ocean. This groundwater flow is caused by gravity. Both the vertical unsaturated flow and the lateral saturated flow below the water table can be described by classical D"Arcy theory of non turbulent flow through porous media, Q = kiA. This equation states that the rate of flow Q (ft3/day) equals the permeability of the porous media k (ft/day) times the hydraulic gradient i (ft/ft) which is the drop in elevation in feet that a particle of water undergoes while moving a distance in feet through the porous media, times the cross sectional area A (ft2) through which the water is flowing. The actual average velocity of the particle of water through the soil is the permeability times the hydraulic gradient divided by the porosity of the soil (V=ki/N). The porosity of a soil is the volume of the voids divided by the total volume of the soil, expressed as a ratio. When the sand is 100% saturated the voids are filled with water. If the sand is allowed to drain, some of the water is held in the voids by capillarity, but most of the water drains out. The effective porosity is the volume of the voids that have drained divided by the total volume. The porosity and the effective porosity measured on several samples of the sand retrieved from test borings are approximately 0.25 and 0.20 respectively. If after some date in late autumn, November 1 for instance, none of the rain transpires and the upper 4-6 feet of silty soil are resaturated, the rain again begins to percolate down to the water table at a rate indicated by the "Troxler" tests of about ½ foot per day. When that water reaches the water table and the downward flow rate exceeds the

rate at which the water is draining away, the water table starts to rise. At some date in spring, May 1 for instance, the rain no longer leaves the upper soil and about 110 days later at Well #122, where the water table is 55 feet below ground surface, (55 ft/0.5 ft/day) the last of the winter rain reaches the water table. Then at Well #122, at the head of the watershed where the water drains primarily vertically with little lateral input, the rate of the drop in the water table times the effective porosity of the soil equals the rate that ground water is flowing away. This process is shown for the typical years 2005 – 2007 in Fig 9. This flow rate depends on the lateral hydraulic gradient in the area, ie the elevation of the water table divided by the distance to the ocean, and doesn"t change very much during any year. Fig. 10 shows how this rate of drainage from the water shed depends on the elevation of the water table. The rate of water table drop when there is no recharge occurring, times the effective porosity equals the recharge rate for that year. Fig. 10 shows the average recharge rate from 1986 to 2012 to be about 1.5 feet per year. Fig. 11 shows a flow net drawn to show the flow pattern in a vertical slice of sand one foot thick from MVC #8 and Well #122 to Town Cove 12,000 feet away, assuming a steady downward percolation to the water table of 1.5 feet per year. This water then flows laterally through approximately 100 feet of sand overlying the impermeable clay strata to the pond or under the pond to the ocean. If the amount of water flowing Q, flowing from 1.5 feet of recharge, the cross sectional area A, and the distances are known, the permeability can be calculated. The calculated permeability of 200 ft/day compares reasonably with the permeabilities of 100 to 200 ft/day that have been measured on disturbed samples of the sand from test borings. This reaffirms the use of 1 ½ feet of rain per year as the average rate of ground water recharge.
The time of travel of water particles from various places in the water shed can also be calculated. A time of travel of 20 to 30 years from the head of the water shed indicates that using a multi year average for the recharge amount is reasonable. Another estimate of the yearly ground water recharge is based on the rain between November 1 and May 1. From 1985 to 2013 the average rain for those six wet months was 24 inches. Subtracting the seven inches that is held in the upper soil gives an annual recharge of 17 inches.

The rate of flow of ground water south to the pond and ocean is greater when the elevation of the ground water table at the head of the water shed is higher than when it is lower, because of the greater hydraulic gradient. Fig. 4 shows that in 1987,1997 and 1998, the ground water table at Well #122 was above elevation +30 NGVD. In the years 1989, 1996 and 2002, the groundwater table at Well #122 was below +22 NVGD. The variation of hydraulic gradient from 30/12000 to 22/12000 would result in a decrease in groundwater flow rate of about 30%. This variation in flow from year to year is a result of variations in the yearly amount of rain recharge in the water shed. This is shown in Fig. 4 in the amount of rain that occurred in the months of November through April preceding the seasonal lows and highs of the water table. Although the change of ground water flow varies up to 30% within a few years, it doesn"t vary more than about 10% within a given year since the hydraulic gradient doesn"t change more than 10%. During a year of more recharge, the hydraulic gradient must increase to move the increased amount of water toward the ocean.

b) Rain Water Recharge of Ground Water Shed

The rate of groundwater flowing to the pond and ocean equals the yearly feet of recharge times the ground water shed area. Arthur N. Strahler (1972) describes in detail the recharge process and the various estimates of ground water recharge for Cape Cod that have been used by hydrologists. He concludes that the average recharge into the sandy outwash areas of Cape Cod is 16" to 20" per year. This is supported by the calculations above. The average rate of ground water flowing to the pond and the ocean is 1.5 ft/yr x 6250 acres x 43560 ft2/acre which equals 395,307,000 ft3/yr which equals 12.5 ft3/second.

c) Precipitation on The Pond.

The average rainfall of 3.8 feet per year minus the average annual reservoir evaporation of about 2 feet, as given in “The Water Encyclopedia” for Maine and Massachusetts, (1990), gives an average rain into the pond of 1.8 feet x 700 acres x 43560 ft2/acre equal to 55,000,000 ft3/yr which equals 1.7 ft3/second. Most of the evaporation occurs during the warm summer months, so the rain going into the pond from November to May is probably closer to 3 ft3/second.

d) Ground Water Flow into the Pond

When the pond is low and the beach channel has just been closed by wave action, the flow of water out through the barrier beach should be zero if the water elevation in the pond is the same as the average ocean elevation. The effective ocean elevation at the beach front is raised by wave action, described by Urish & Ozbilgin (1989). There are very few days when the waves are less than three feet so it is assumed that when the pond elevation is +3 NGVD, flow through the barrier beach, in or out, is zero. The rate of pond rise times the pond area minus the stream flow when the channel flow is zero and rain flow is zero, equals the ground water flow rate into the pond. The rate of pond rise after channel closings is marked on the plots of pond elevation versus time from 1994 to 2008 in Fig. 7. These rates are given in Table II. The stream flow rate for the same date is subtracted from the pond volume increase rate, giving the rate of ground water flow into the pond. The average of these rates of ground water flow into the pond is 11.5 ft3/sec.

e) Flow in the Beach Channel

When the pond elevation approaches +5 NGVD, plans are made by the Pond Commissioners to excavate a channel through the barrier beach. Four primary factors are considered: the height of the pond surface above the ocean; the effect the lowering of the pond and the channel would have on the flora and fauna: the salinity and dissolved oxygen of the pond: and the anticipated weather. The health of the flora and fauna ( oysters, clams, crabs finfish and birds) depend on flushing out the brackish water and an inflow an inflow of ocean water with daily tidal flow. To maximize the tidal exchange between the pond and the ocean, the channel through the beach should be as wide and deep as possible. To maximize the draining of the lowlands, the pond should remain open to the ocean as long as possible. The depth and width of the channel are maximized by excavating the channel at the narrowest portion of the barrier beach with access to the deeper areas of the pond just north of the beach, which results in the concentration of the power of the out flowing water on the smallest volume of sand. Excavation of the channel near the time of a spring tide with a north wind results in the maximum elevation differences between the pond and the ocean with a resulting out flow of up to 5000 ft3/sec., and maximizes the depth and width of the channel scoured through the beach.

Generally two tidal cycles (15-20 hours) are required to drain the pond to ocean level, as shown in Fig. 8. A tidal fall of one foot of the pond surface in six hours is an average flow of 1200 ft3/sec out through the channel and 27 million cubic feet of water or about 16% of the total volume of the pond flows out with each tide(Fig.2) leaving 84% of the brackish water. If perfect mixing occurs with the following tidal inflow, the next one foot tidal out flow leaves 84% of the remaining brackish water. About 13 tidal out flows ( 0.84 raised to the $13^{th}$ power = 0.10) will leave only 10% of the brackish water . Inflow of streams, groundwater and rain, make the calculation approximate. A tidal fall of ½ foot would require about 26 tidal out flows to remove 90% of the brackish water. Generally there is measurable stratification as the fresh water from the Town Cove streams flows out over the heavier ocean water, however a south west wind of 15-20 MPH and the incoming tidal flow result in mixing in the central portions of the pond and the salinity of the pond water increase from about 30% of that of the ocean to 75% within a week of a “good” opening. The salinity along the west shore is measured periodically with a “YSI” conductivity meter. (C= 45 milli siemens = 32 PPT salt). As the wind and waves gradually fill the channel with sand, the tidal flow decreases until the bottom of the channel is up to about + 2.5 NGVD. Even after the flow in through the channel stops, the waves running up the barrier beach raise the effective ocean level and ocean water continues to flow into the pond. Strong storms cause the waves to break over the barrier beach and have, during hurricanes, raised the pond level enough so that a channel reforms and the pond opens “naturally”. If the pond remained closed for more than a year without ocean water exchange, the pond would become much fresher and the flora and fauna would change dramatically. An attempt was made to measure the tidal flow in the channel and subtract the change of pond elevation during the same time in order to calculate the ground water inflow. The change of pond elevation could not be measured closer than about 0.02 feet over a period of an hour which is a volume change of about 150 ft3/sec. and the flow in the channel was 600 to 1000 ft3/sec. These flow rates were enough to obscure the much lower rates of ground water and stream water inflow.

f) Flow Through the Barrier Beach

The elevations of the pond and the water table in wells Q2 and Q3 were plotted versus time for typical periods as shown in Fig. 13, 14 and 15. These plots allow the calculation of the pond water flow out and the ocean water flow in through the barrier beach using Q = kiA. The permeability k of samples of the coarse beach sand from several locations was found to be 700 +- 50 ft/day. The hydraulic gradient i is equal to the difference in elevation of the water table between wells Q2 and Q3, divided by the horizontal distance between the wells (70 ft). The cross sectional flow area was taken as the depth of the ground water above the impermeable peat layer (13 ft) times the length of the barrier beach between the ocean and the ponds (9000 ft). The latter value is the most uncertain factor in the calculation, as the depth to the peat layer was only measured in a limited zone. The three figures (13,14,15) show how the flow in and out through the barrier beach varies with pond and ocean levels and with size of the waves. These calculations show that the water flow in and out through the barrier beach is of the same order of magnitude as the ground water and stream flow and must be considered in the hydrology of the pond.

g) Water Flow Into Tisbury Great Pond

The water flow into the pond from the watershed is shown for typical ten day periods in 2012 during three pond elevations, in Fig. 16. These calculations are done only for periods during which the water flow through the barrier beach was measured, based on data from the monitoring wells on the beach. These calculations indicate that a significant amount of ground water from the water shed must bypass the pond and flow under or around the pond to the ocean.

Plans are being made to drag conductivity meter along the bottom of the ocean just off shore to try and detect the fresh water that is coming out under the pond.

h) Water Budget

Tables III and IV are summations of the flows calculated previously. Table III is a compilations of an average yearly water budget of the Tisbury Great Pond watershed assuming the pond is open to the ocean 42% of the year. Assuming no change in storage, The annual input should match the annual output. Table IV is a compilation of average flows of fresh water into the pond.

5. CONCLUSIONS

a) Measurements of the elevation of the ground water table have allowed calculations of the watershed area and flow rates. Measurements of the rain fall have allowed calculations of the recharge rate and flow rates within the watershed. Measurements of the stream flows and flow through the barrier beach have allowed calculations of the total water flow into the pond and flow under the pond to the ocean. These measurements should be continued to confirm the calculations.

b) Although the average yearly stream flow of 317 million cubic feet is close to the average yearly ground water flow of 287 million cubic feet. The stream flow depends on the rainfall of that year and can vary from 123 to 503 million cubic feet per year whereas the ground water flow depends on a multi year average and is more constant.

c) These measurements over the last thirty years show how important it is to not base conclusions regarding surface and ground water flows on measurements from just a few years.

TABLE I

MVC TEST BORING LOGS
NGVD Elevations-ft

| Boring | GWT elev. | Strata elev. | Soil Type | k-ft/day | Elev. of screens |
|---|---|---|---|---|---|
| 4 | +18 to +23 | +95 to -35 | fine to coarse sand | 30 to 60 | +15 |
| | | -35 to -45 | silty sand | 5 to 12 | -25 |
| | | -45 to -105 | silty sand | 1 to 2 | -65 |
| | | -105 to -165 | clayey till | 0.01 | |
| 5 | +14 | 46 to -91 | fine to coarse sand | 50 to 200 | +9 |
| | | | | | -41 |
| | | -91 to -111 | clayey till | 0.01 | -91 |
| 6 | +5 to +7 | +27 to -76 | fine to coarse sand | 20 to 120 | -3 |
| | | -76 to -148 | silty sand | 10 to 40 | -76 |
| | | -148 to -173 | clay | 0.001 | -145 |
| 8 | +20 to +25 | +72 to +11 | fine to coarse sand | 100 | +16 |
| 9 | +21 | +92 to +16 | fine to coarse sand | 100 | +20 |
| 10 | +4 | +15 to -73 | fine to coarse sand | 100 to 200 | +10 |
| | | -73 to -170 | silty sand | ½ to 1 | -65 |
| | | -170 to -190 | clayey till | 0.01 | -165 |

HEALY ½" Pipe Probes on barrier beach

| | | | | |
|---|---|---|---|---|
| P1 | +2 | +2 to -13 | coarse Sand | 600 |
| | | -13 to -23 | peat | <0.01 |
| P2 | +2 | +2 to -8 | coarse sand | 360 to 450 |
| | | -8 to -13 | peat | < 0.01 |
| | | -13 to -18 | coarse sand | 300 to 500 |
| | | -18 to -28 | sand | 100 to 240 |

# TABLE II

WATER FLOW INTO TISBURY GREAT POND –
POND ELEV. +3, NO FLOW THROUGH BEACH, CHANNEL CLOSED

| YEAR | DAY | POND VOLUME INCREASE FT³/SEC | TOTAL STREAM INFLOW FT³/SEC | GROUND WATER INFLOW FT³/SEC |
|---|---|---|---|---|
| 1993 | 10 | 19 | – | |
| | 100 | 22 | – | |
| | 185 | 10 | – | |
| 1994 | 0 | 30 | 10 | 20 |
| | 85 | 30 | 18.5 | 11.5 |
| | 145 | 14 | 8.5 | 5.5 |
| | 260 | 15 | 3.5 | 11.5 |
| 1995 | 30 | 13 | 6 | 7 |
| | 145 | 13 | 4 | 9 |
| | 260 | 11 | 2.5 | 8.5 |
| 1996 | 0 | 13 | 6 | 7 |
| | 280 | 24 | 12 | 12 |
| 1997 | 25 | 25 | 17 | 8 |
| | 190 | 38 | 11 | 27 |
| | 150 | 27 | 17.5 | 9.5 |
| | 345 | 17 | 7.5 | 9.5 |
| 1998 | 40 | 35 | 20 | 15 |
| | 250 | 15 | 10.5 | 4.5 |
| 1999 | 30 | 15 | 15 | 7 |
| | 160 | 16 | 5.5 | 10.5 |
| | 270 | 13 | 5.5 | 7.5 |
| 2000 | 25 | 22 | 10 | 12 |
| | 125 | 30 | 15 | 15 |
| | 195 | 13 | 6 | 7 |
| | 280 | 13 | 3 | 10 |
| 2001 | 45 | 19 | 5.5 | 13.5 |
| | 110 | 30 | 15 | 15 |
| | 200 | 13 | 6 | 7 |
| | 335 | 12 | 3.5 | 8.5 |
| 2002 | 135 | 13 | 6 | 7 |
| | 340 | 19 | 9.5 | 9.5 |
| 2003 | 45 | 25 | 10 | 16 |
| | 110 | 27 | 19 | 8 |
| | 155 | 32 | 19 | 13 |
| | 220 | 15 | 6.5 | 8.5 |
| 2004 | 10 | 30 | 13 | 17 |
| | 90 | 25 | (13) | (12) |
| | 160 | 25 | (13) | (12) |
| | 340 | 19 | (8) | (11) |
| 2005 | 90 | 35 | (15) | (20) |
| | 265 | 22 | 5 | 17 |
| | 350 | 20 | 10 | 10 |
| 2006 | 30 | 27 | 11 | 16 |
| | 100 | 20 | 8 | 12 |
| | 260 | 15 | 7.5 | 7.5 |
| | 360 | 19 | 8 | 11 |
| 2007 | 50 | 27 | 13 | 14 |
| | 155 | 15 | 4 | 11 |
| | 210 | 15 | 8 | 7 |
| | 350 | 27 | 7 | 20 |
| 2008 | 125 | 24 | 7 | 14 |
| | 205 | 20 | 9 | 11 |

( ) ESTIMATE BASED ON MILL BROOK FLOW

15 YEAR AVG 11.5 FT³/SEC
= 362 × 10⁶ FT³/YR

NOT CORRECTED TO ACCOUNT FOR BARRIER BEACH FLOW

TABLE III

TISBURY GREAT POND WATERSHED- AVERAGE YEARLY WATER BUDGET
1994 - 2012 Pond ; Open 42%, Closed 58%

| INPUT to WATERSHED | million ft3/year |
|---|---|
| Groundwater Recharge from Rain<br>1.5 feet/year x 6250 acres x 43560 ft2/acre | 408 |
| Stream Flow (Mill Brook + Tiasquam River) | 317 |
| Rain minus Evaporation on Ponds<br>(3.9 – 2.0 ) feet/year x 760 acres x 43560 ft2/acre | 63 |
| TOTAL INPUT | 788 |
| OUTFLOW FROM WATERSHED | |
| Flow out through channel the day of opening<br>3.3 Pond Openings/year x 3 ft x 29,000,000 ft2 | 287 |
| Flow out through channel when Pond is open, low and tidal<br>Ground water + stream flow + rain<br>(408 +317 + 63) x 42% | 331 |
| Outflow through barrier beach when pond is closed<br>4 ft3/sec x (365 x 1440 x 60) sec/year x 58% | 74 |
| | 692 |
| Seepage out of watershed bypassing Pond, 788 minus 692 = | 96 |
| TOTAL OUT PUT | 788 |

TABLE IV

FRESH WATER FLOW INTO TISBURY GREAT POND

TYPICAL YEAR

| | Million ft3/year Average | % of Total |
| --- | --- | --- |
| STREAM FLOW<br>Mill Brook + Tiasquam River | 317 | 46 |
| GROUNDWATER<br>Recharge x groundwater shed<br>minus groundwater bypassing Pond (408 – 96) | 312 | 45 |
| DIRECT PRECIPITATION<br>minus Evaporation | 63 | 9 |
| | 692 | |

FIGURE 1
Tisbury Great Pond Watershed
Scale 1:25,000 (1" = 2083')
February 27, 2009
Rev. August 8, 2013

0' 500' 1000' 2000' 4000' 8000'

Water Shed Areas

| | |
|---|---|
| Tiasquam River | 1740 Acres |
| Mill Brook | 2940 Acres |
| Outwash groundwater recharge area | 6250 Acres |
| Tisbury Great Pond and Black Point Pond | 760 Acres |
| Total | 11690 Acres |

| WELL | SIZE | LIP ELEV. NGVD 1929 |
|---|---|---|
| Healy 122 | 1 ½" | +81.85' |
| Green | 1 ¼" | +56' |
| Mitchell | 4" | +46.39' |
| WT 101 | 2" | +76.77' |
| UA 16 | 2" | +32.80' |
| F 1 | 4" | +20.60' |
| S. Meadow | 4" | +14.74' |
| Honey | 1 ¼" | +36.14' |
| Q 1 | 1 ¼" | +23.79' |
| MVC #4 | 3 ¾" | +96.28' |
| MVC #5 | 3 ¾" | +48.9' |
| MVC #6 | 3 ¾" | +29.56' |
| MVC #8 | 2" | +76.69' |
| MVC #9 | 2" | +96.21' |
| MVC #10 | 3 ¾" | +14.51' |
| BANK | 2" | +87' |

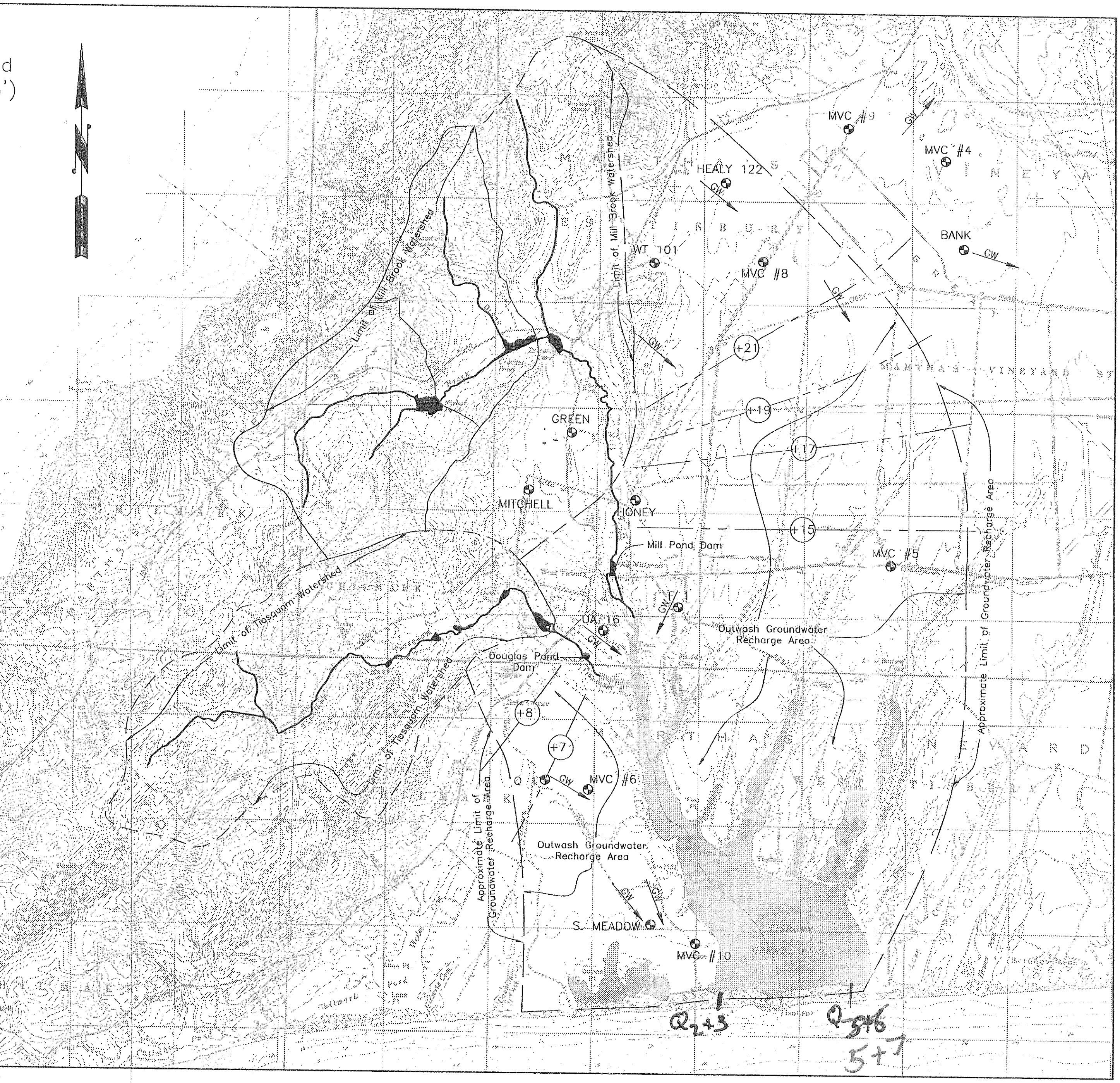
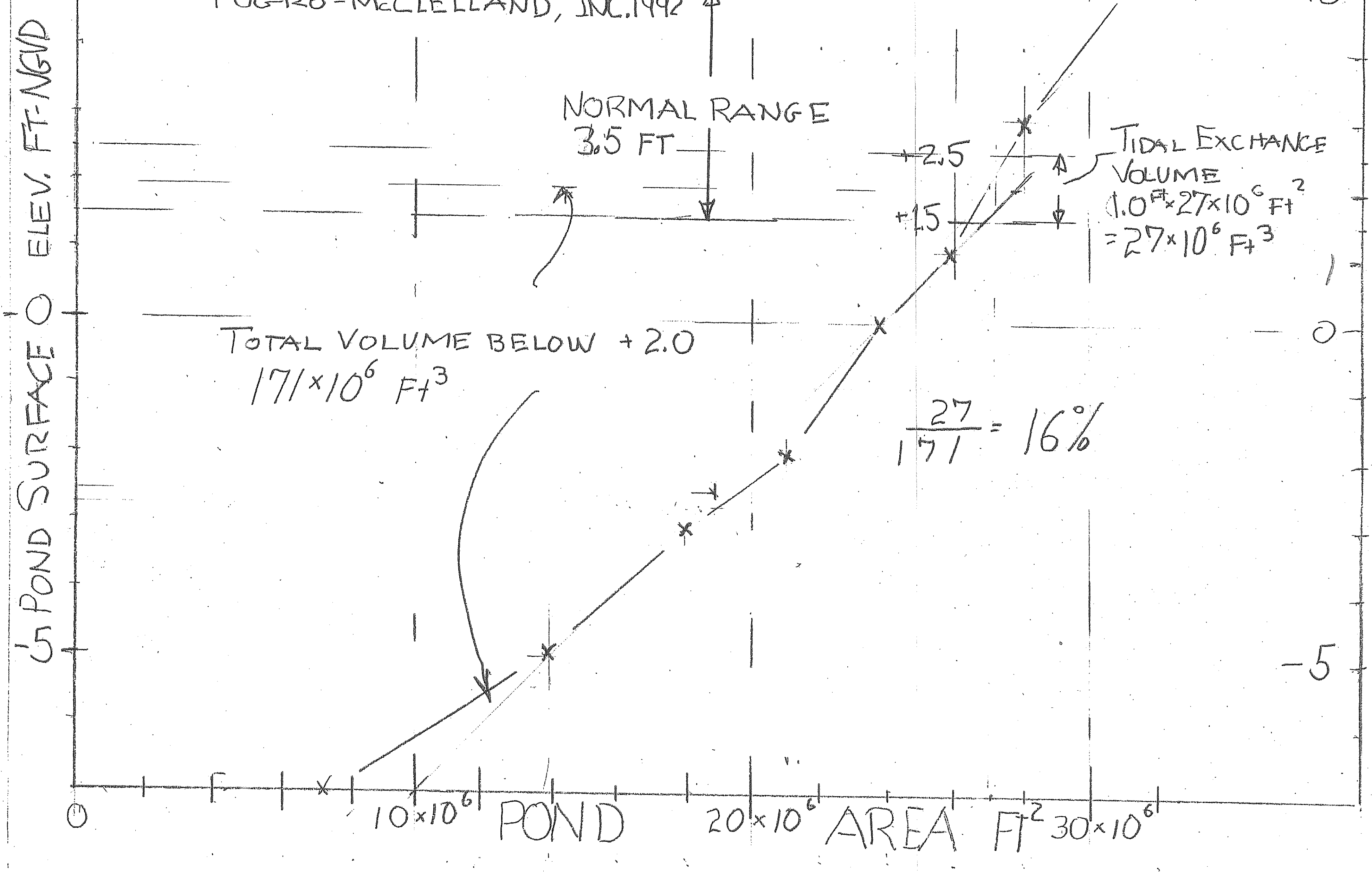


FIGURE 2 - TISBURY GREAT POND SURFACE - $Ft^2$

FUGRO-McCLELLAND, INC. 1992



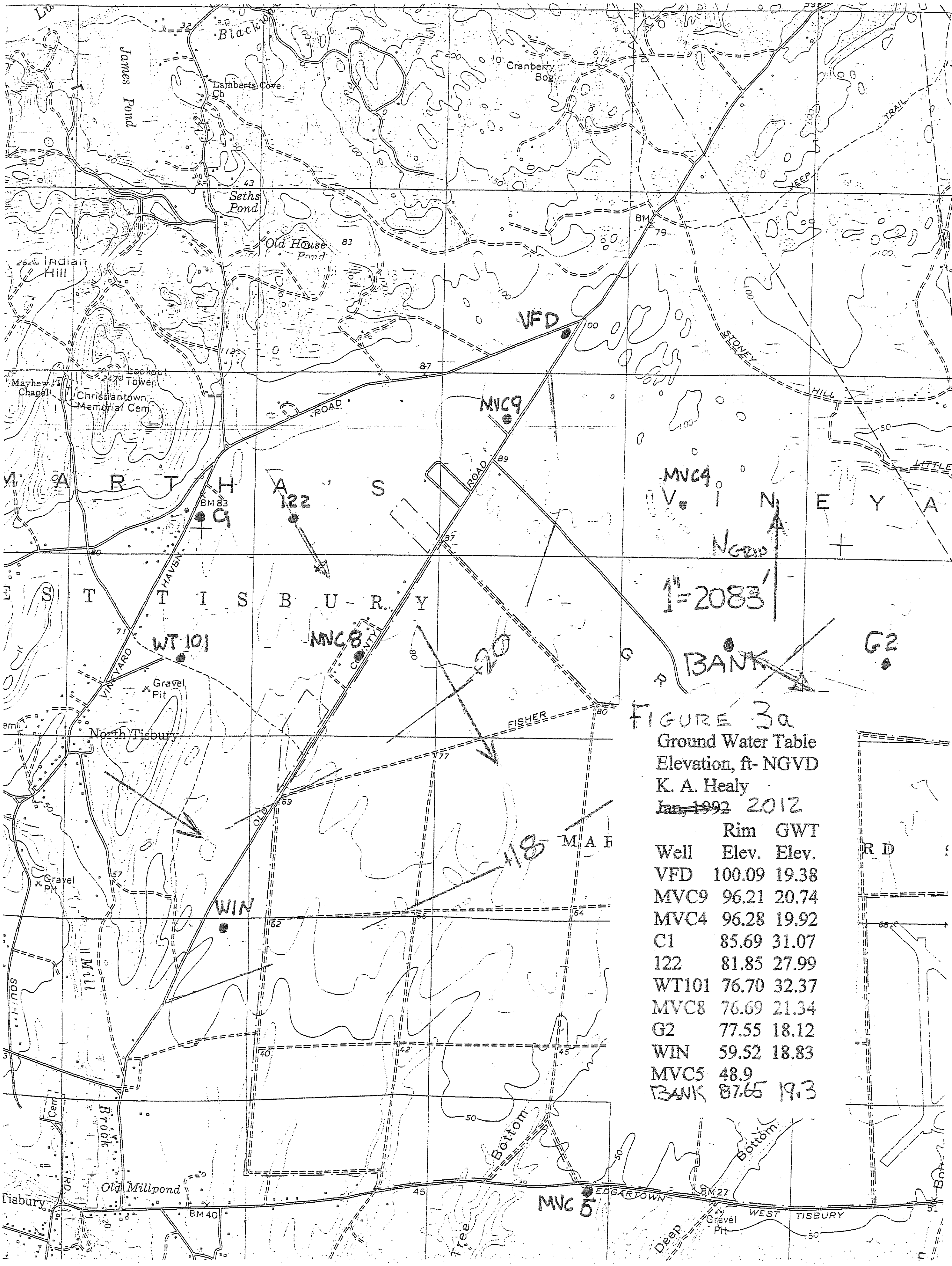
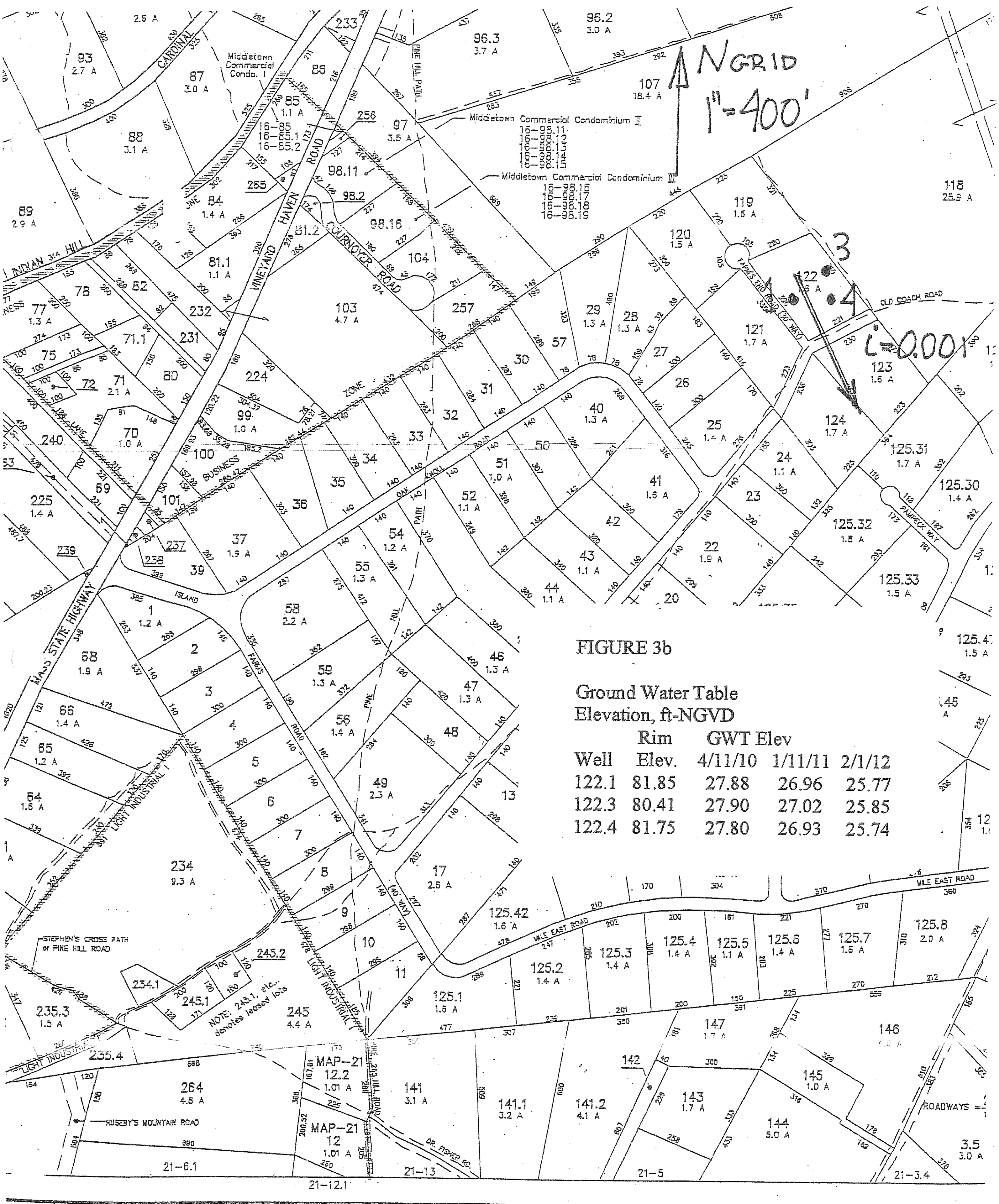



FIGURE 3a

Ground Water Table Elevation, ft- NGVD
K. A. Healy
~~Jan, 1992~~ 2012

| Well | Rim Elev. | GWT Elev. |
|---|---|---|
| VFD | 100.09 | 19.38 |
| MVC9 | 96.21 | 20.74 |
| MVC4 | 96.28 | 19.92 |
| C1 | 85.69 | 31.07 |
| 122 | 81.85 | 27.99 |
| WT101 | 76.70 | 32.37 |
| MVC8 | 76.69 | 21.34 |
| G2 | 77.55 | 18.12 |
| WIN | 59.52 | 18.83 |
| MVC5 | 48.9 | |
| BANK | 87.65 | 19.3 |




# FIGURE 3b

Ground Water Table Elevation, ft-NGVD

| Well | Rim Elev. | GWT Elev 4/11/10 | GWT Elev 1/11/11 | GWT Elev 2/1/12 |
|---|---|---|---|---|
| 122.1 | 81.85 | 27.88 | 26.96 | 25.77 |
| 122.3 | 80.41 | 27.90 | 27.02 | 25.85 |
| 122.4 | 81.75 | 27.80 | 26.93 | 25.74 |

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LEGEND

| | | | |
|---|---|---|---|
| ACREAGE | A | ZONE LIMIT | |
| RECORD DIMENSION | 100 | RIGHT OF WAY/ACCESS | R/W |
| SCALED DIMENSION | 100 S | COMMON OWNERSHIP | |
| WATER | | WETLANDS | |

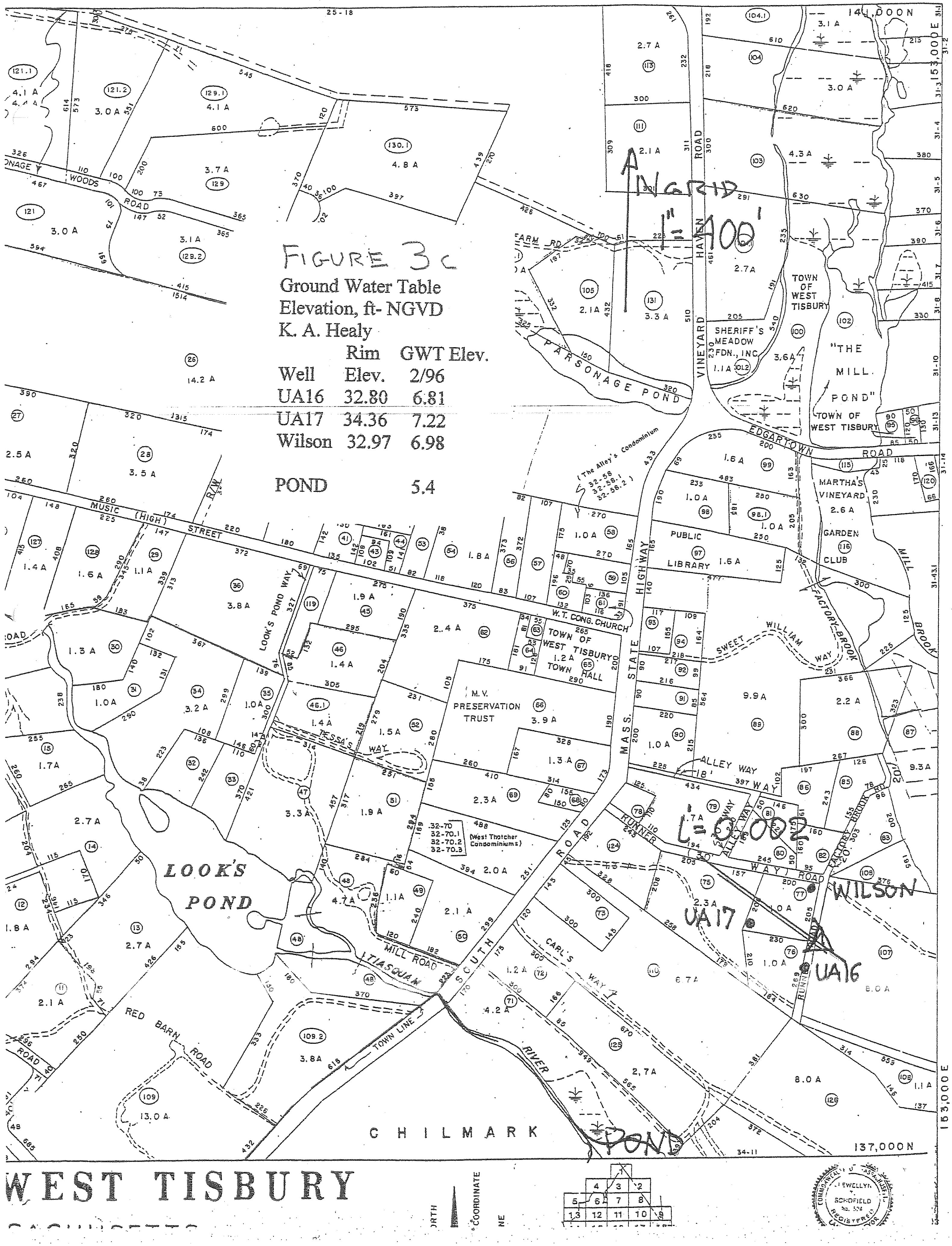
FIGURE 3c
Ground Water Table
Elevation, ft- NGVD
K. A. Healy
Well Rim Elev. GWT Elev. 2/96
UA16 32.80 6.81
UA17 34.36 7.22
Wilson 32.97 6.98
POND 5.4
INGRID
1" = 400'
i = 0.002
WILSON
UA17
UA16
POND
LOOK'S POND
PARSONAGE POND
"THE MILL POND"
TOWN OF WEST TISBURY
SHERIFF'S MEADOW FDN., INC.
PUBLIC LIBRARY
W.T. CONG. CHURCH
TOWN OF WEST TISBURY TOWN HALL
M.V. PRESERVATION TRUST
MARTHA'S VINEYARD GARDEN CLUB
(The Alley's Condominium 32-58 32-58.1 32-58.2)
(West Thatcher Condominiums)
VINEYARD HAVEN ROAD
STATE HIGHWAY
MASS.
SOUTH ROAD
EDGARTOWN ROAD
MUSIC (HIGH) STREET
LOOK'S POND WAY
TESSA'S WAY
ALLEY WAY
SWEET WILLIAM WAY
FACTORY BROOK
MILL BROOK
RUNNER ROAD
CARL'S WAY
MILL ROAD
TIASQUAM RIVER
RED BARN ROAD
TOWN LINE
PARSONAGE WOODS ROAD
FARM RD
CHILMARK
153,000 E
137,000 N
WEST TISBURY
LEWELLYN T. SCHOFIELD No. 524 REGISTERED

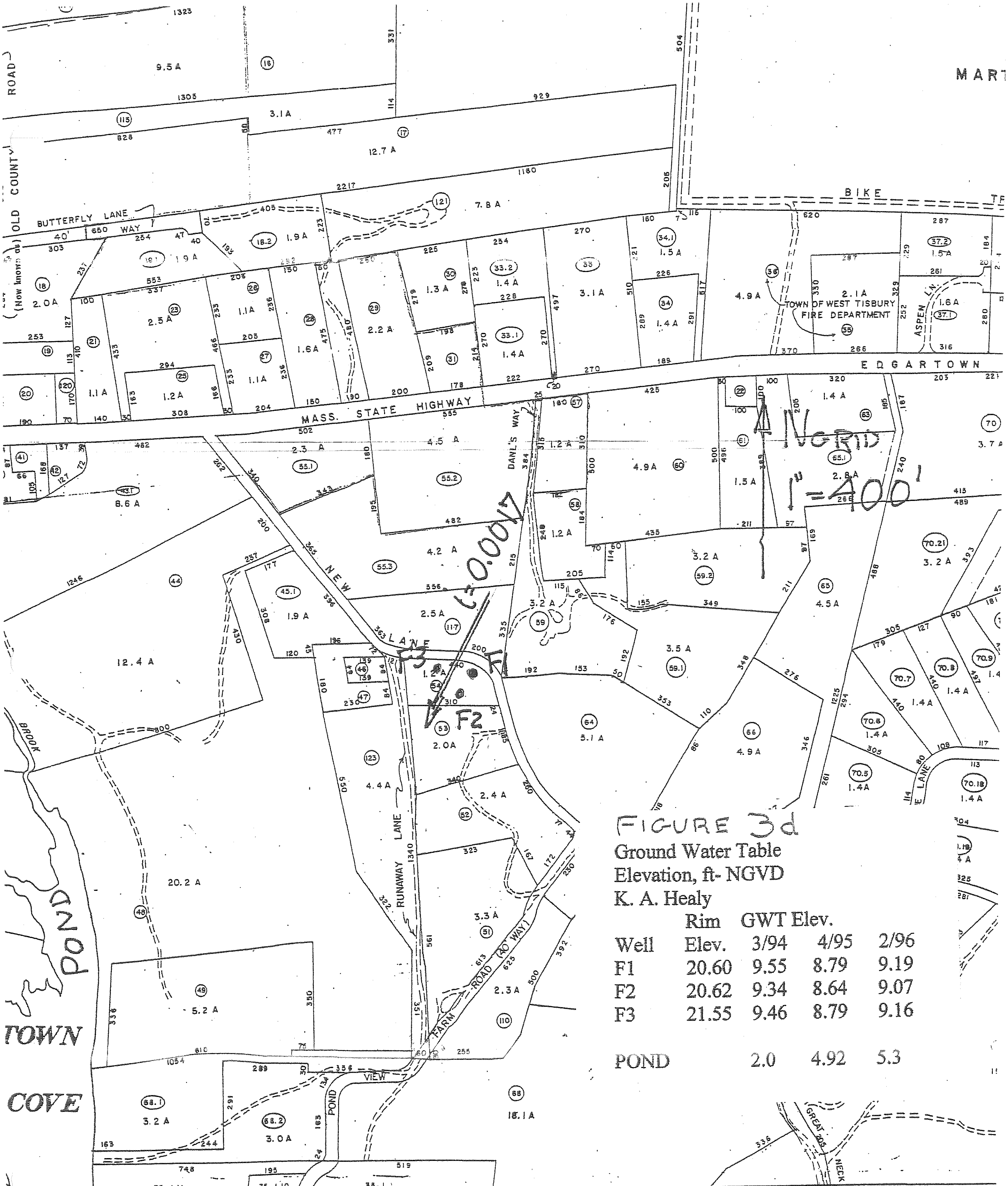


FIGURE 3d

Ground Water Table
Elevation, ft- NGVD
K. A. Healy

| Well | Rim Elev. | GWT Elev. 3/94 | 4/95 | 2/96 |
|---|---|---|---|---|
| F1 | 20.60 | 9.55 | 8.79 | 9.19 |
| F2 | 20.62 | 9.34 | 8.64 | 9.07 |
| F3 | 21.55 | 9.46 | 8.79 | 9.16 |
| POND | | 2.0 | 4.92 | 5.3 |

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PLANS SHOWN HEREIN ARE COMPILED FROM AERIAL PHOTOGRAPHS, DEEDS.

TOWN OF WEST TIS

MASSACHUSETTS

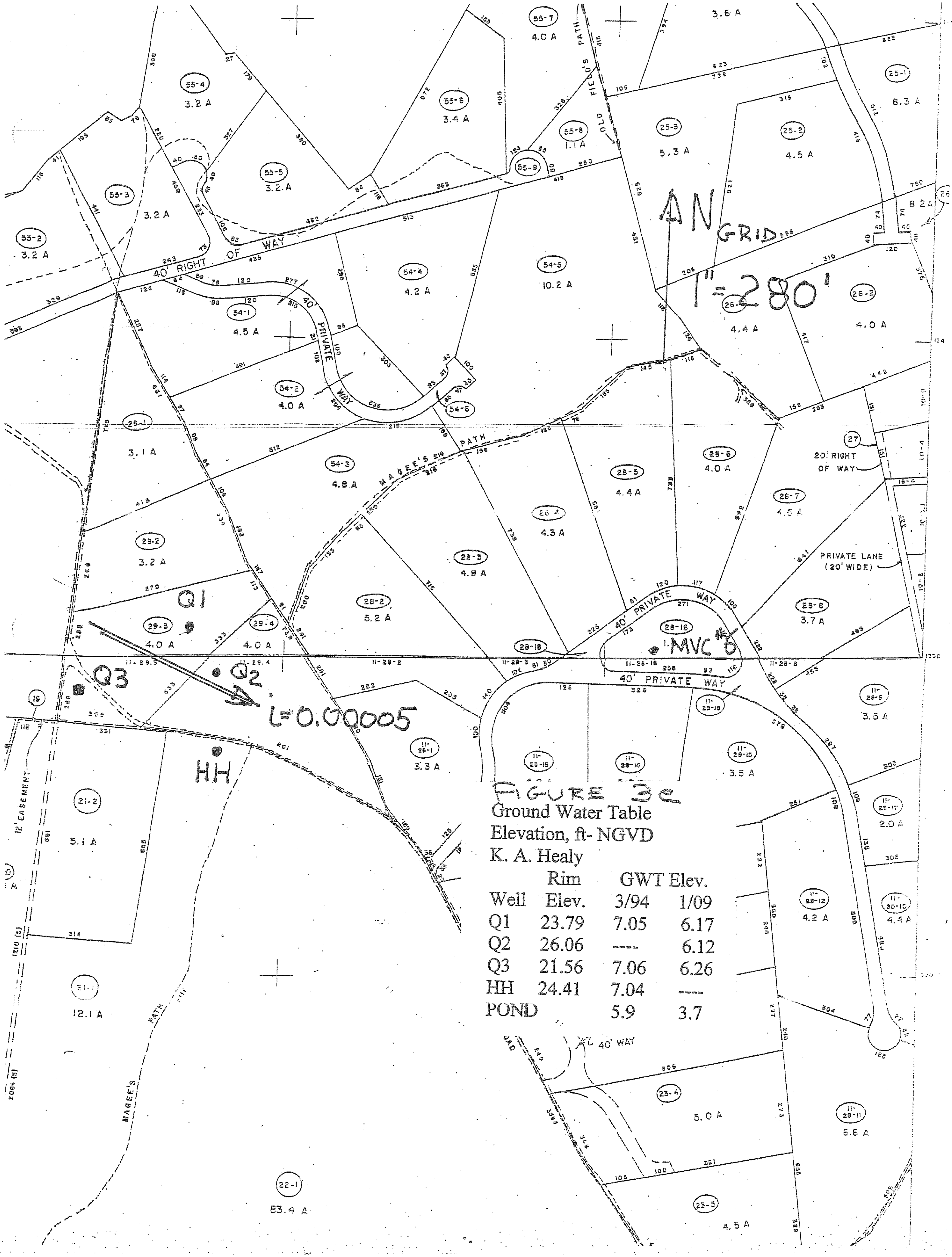



FIGURE 3e
Ground Water Table
Elevation, ft- NGVD
K. A. Healy

| Well | Rim Elev. | GWT Elev. 3/94 | GWT Elev. 1/09 |
|---|---|---|---|
| Q1 | 23.79 | 7.05 | 6.17 |
| Q2 | 26.06 | ---- | 6.12 |
| Q3 | 21.56 | 7.06 | 6.26 |
| HH | 24.41 | 7.04 | ---- |
| POND | | 5.9 | 3.7 |

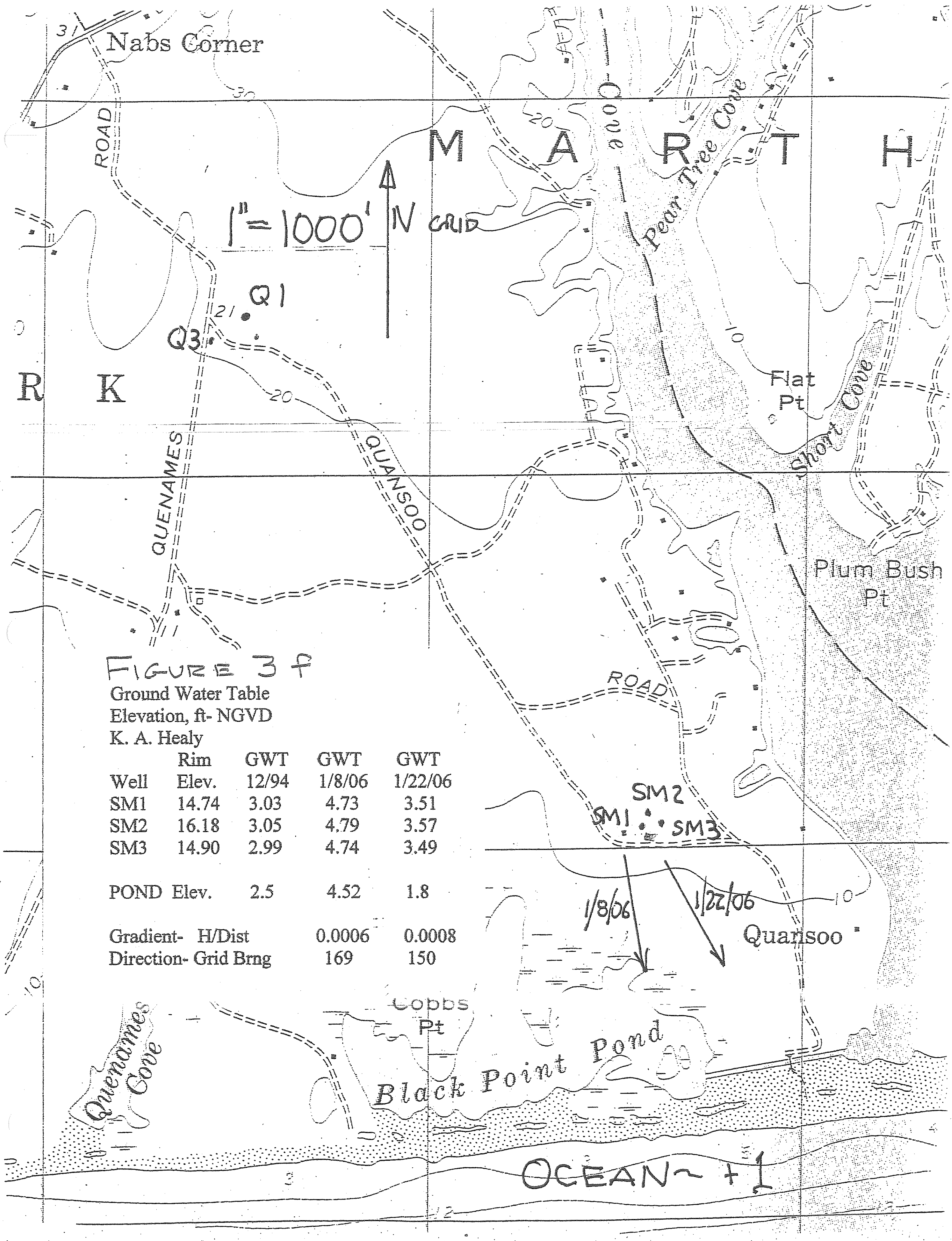



FIGURE 3f

Ground Water Table
Elevation, ft- NGVD
K. A. Healy

| Well | Rim Elev. | GWT 12/94 | GWT 1/8/06 | GWT 1/22/06 |
|---|---|---|---|---|
| SM1 | 14.74 | 3.03 | 4.73 | 3.51 |
| SM2 | 16.18 | 3.05 | 4.79 | 3.57 |
| SM3 | 14.90 | 2.99 | 4.74 | 3.49 |
| POND Elev. | | 2.5 | 4.52 | 1.8 |
| Gradient- H/Dist | | | 0.0006 | 0.0008 |
| Direction- Grid Brng | | | 169 | 150 |

FIGURE 3g

Ground Water Table
Elevation, ft-NGVD
K.A. Healy 4/2009

| BANK Well | Rim Elev. | GWT Elev |
|---|---|---|
| 1. | 87.32 | 19.34 |
| 2. | 85.00 | 19.29 |
| 3. | 87.65 | 19.24 |

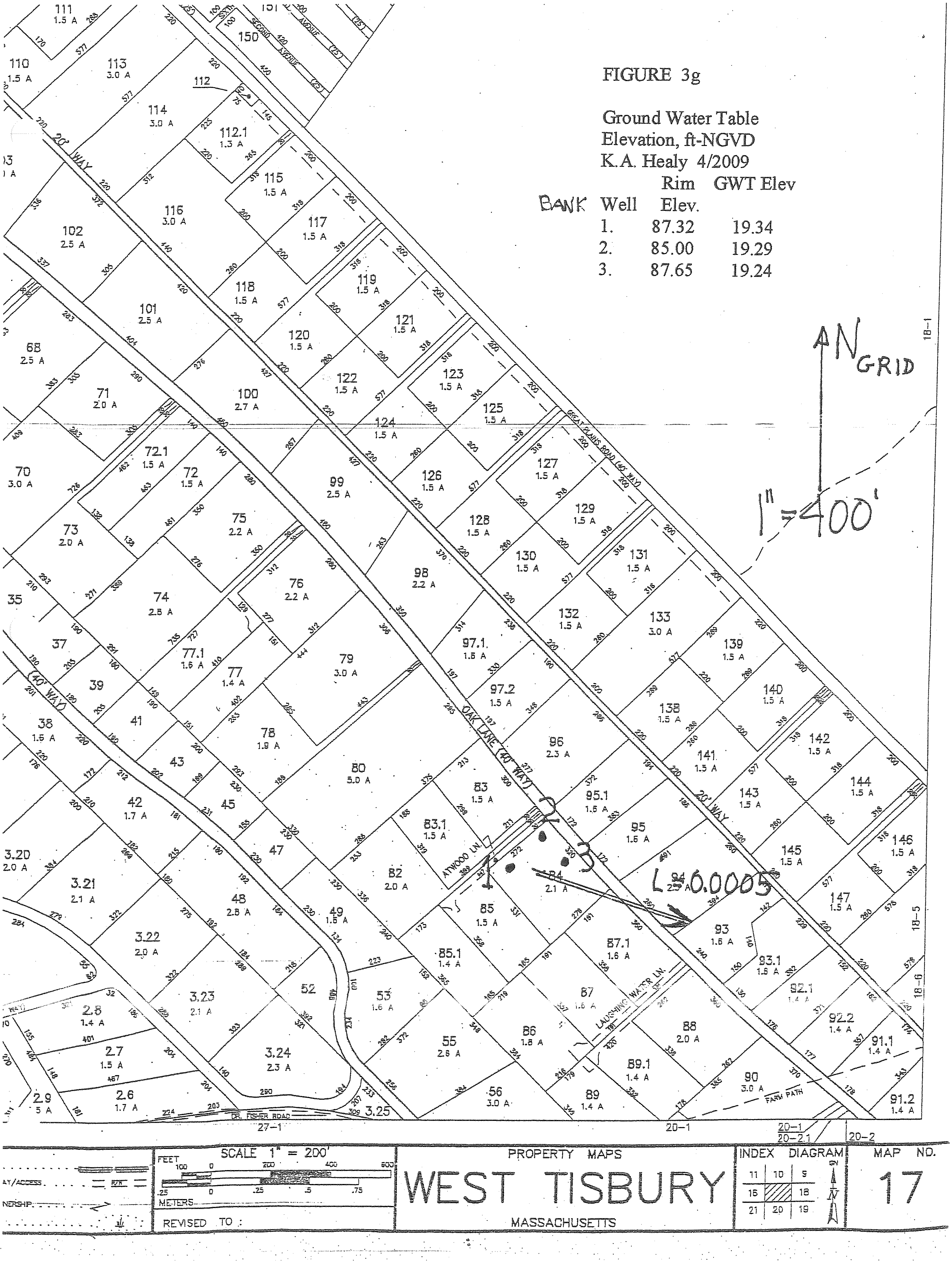


FIGURE 4

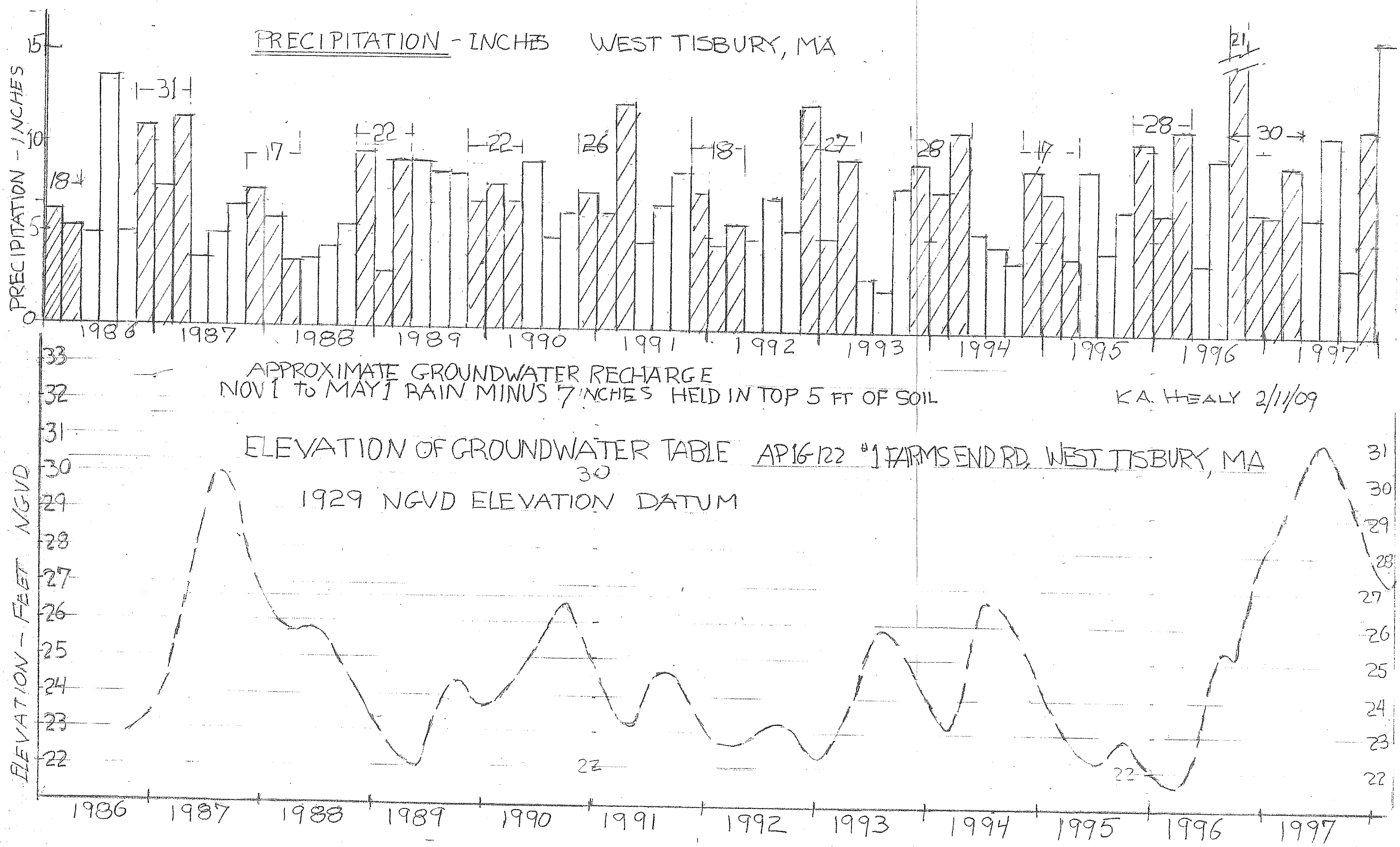
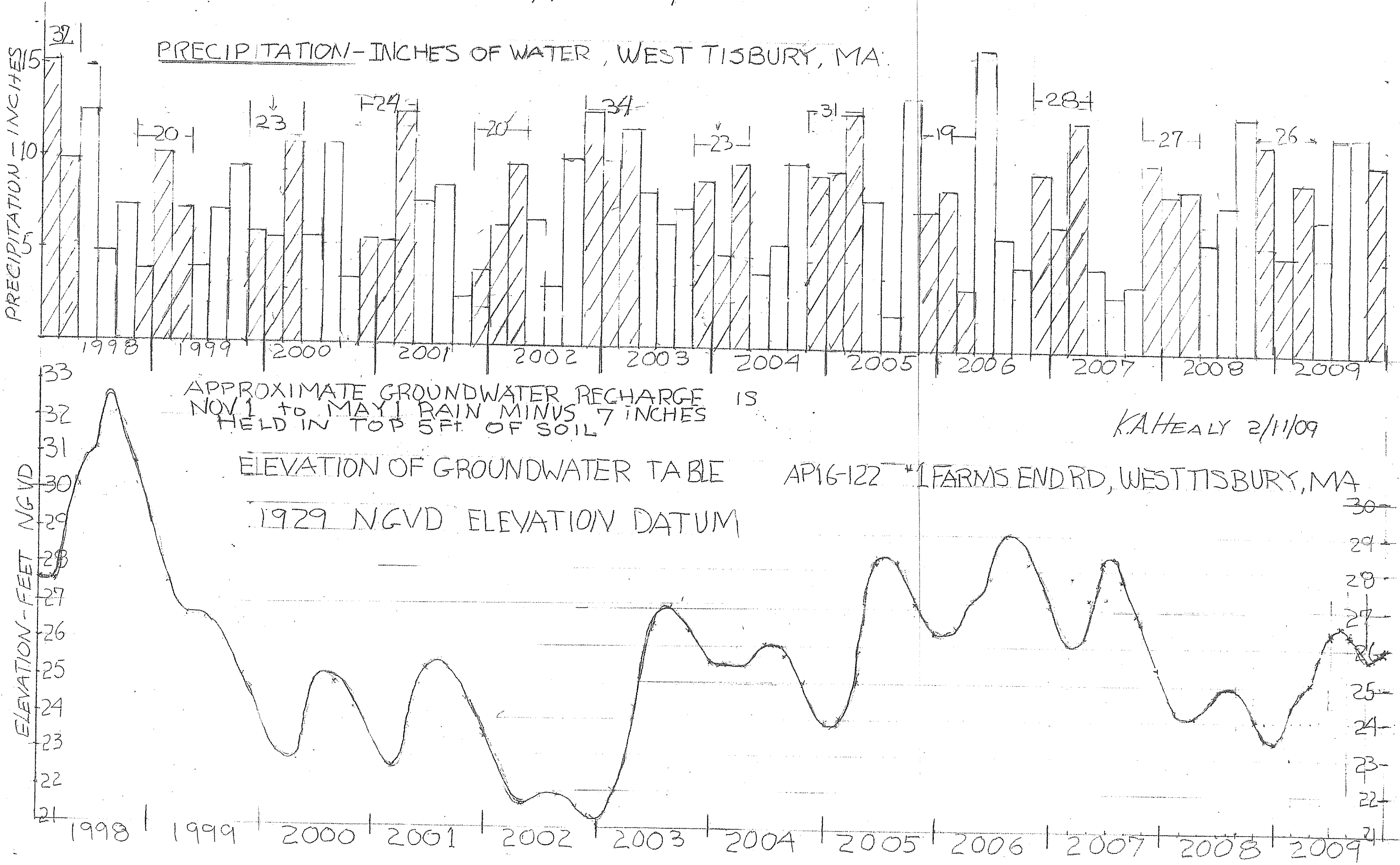

PRECIPITATION - INCHES WEST TISBURY, MA
PRECIPITATION - INCHES
18
31
17
22
22
26
18
27
28
17
28
21
30
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
APPROXIMATE GROUNDWATER RECHARGE
NOV 1 TO MAY 1 RAIN MINUS 7 INCHES HELD IN TOP 5 FT OF SOIL
K.A. HEALY 2/11/09
ELEVATION OF GROUNDWATER TABLE AP16-122 #1 FARMS END RD, WEST TISBURY, MA
1929 NGVD ELEVATION DATUM
ELEVATION - FEET NGVD

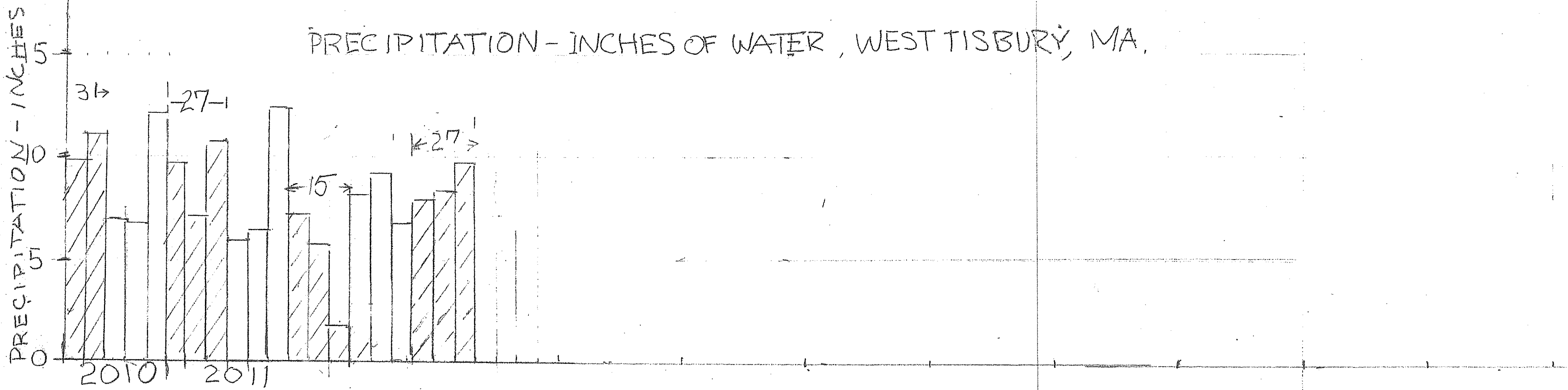
FIGURE 4



PRECIPITATION - INCHES OF WATER, WEST TISBURY, MA
PRECIPITATION - INCHES
APPROXIMATE GROUNDWATER RECHARGE IS NOV 1 to MAY 1 RAIN MINUS 7 INCHES HELD IN TOP 5 Ft OF SOIL
K.A. HEALY 2/11/09
ELEVATION OF GROUNDWATER TABLE AP16-122 #1 FARMS END RD, WEST TISBURY, MA
1929 NGVD ELEVATION DATUM
ELEVATION - FEET NGVD
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009

KAI

# FIGURE 4


PRECIPITATION - INCHES OF WATER , WEST TISBURY, MA.
PRECIPITATION - INCHES
15
10
5
0
31
27
15
27
2010
2011

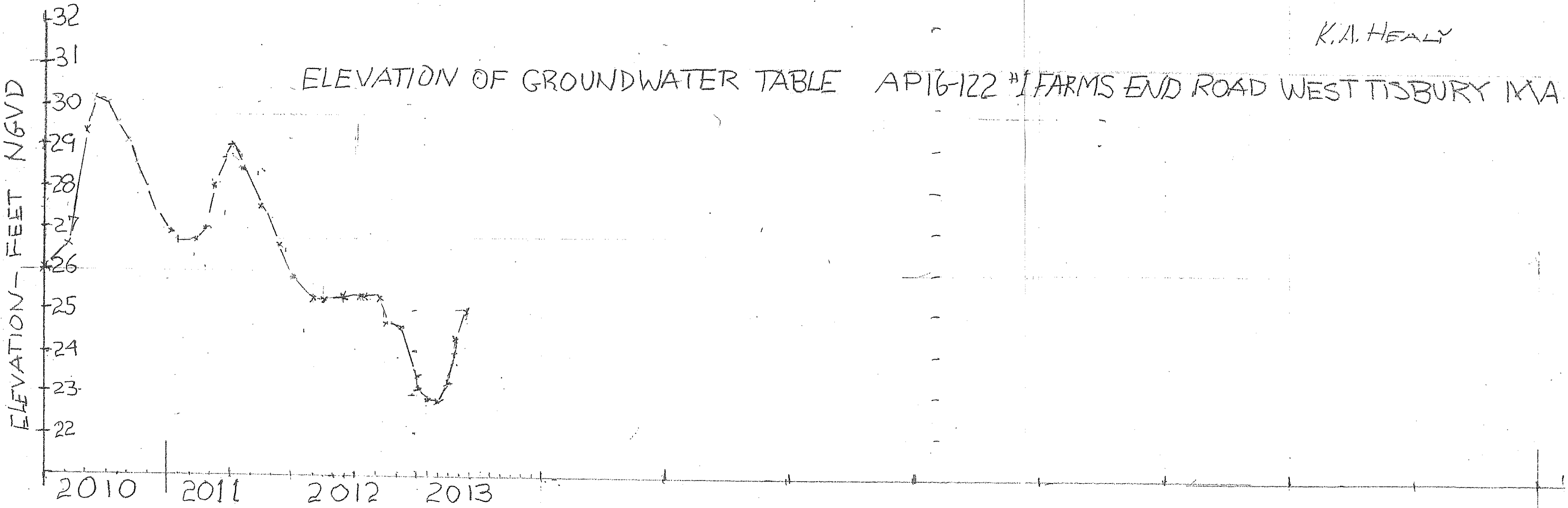

K.A. HEALY
ELEVATION OF GROUNDWATER TABLE AP16-122 #1 FARMS END ROAD WEST TISBURY MA
ELEVATION - FEET NGVD
32
31
30
29
28
27
26
25
24
23
22
2010
2011
2012
2013

FIGURE 5

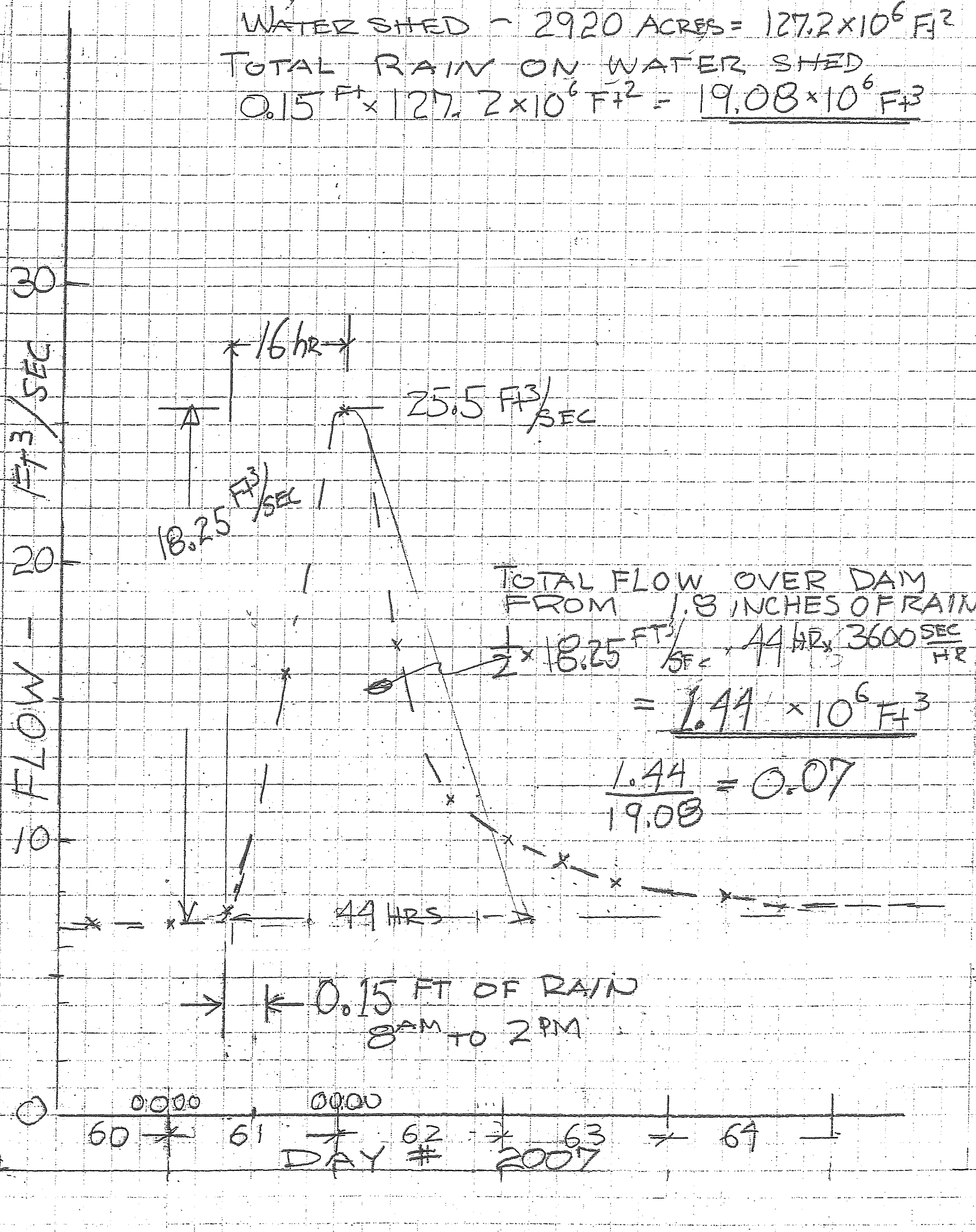
# MILL POND DAM

FLOW AFTER 1.8 INCHES = 0.15 FEET OF RAIN MARCH 2, 2007

WATER SHED ~ 2920 ACRES = $127.2 \times 10^6$ FT$^2$

TOTAL RAIN ON WATER SHED

$0.15\ \text{FT} \times 127.2 \times 10^6\ \text{FT}^2 = \underline{19.08 \times 10^6\ \text{FT}^3}$

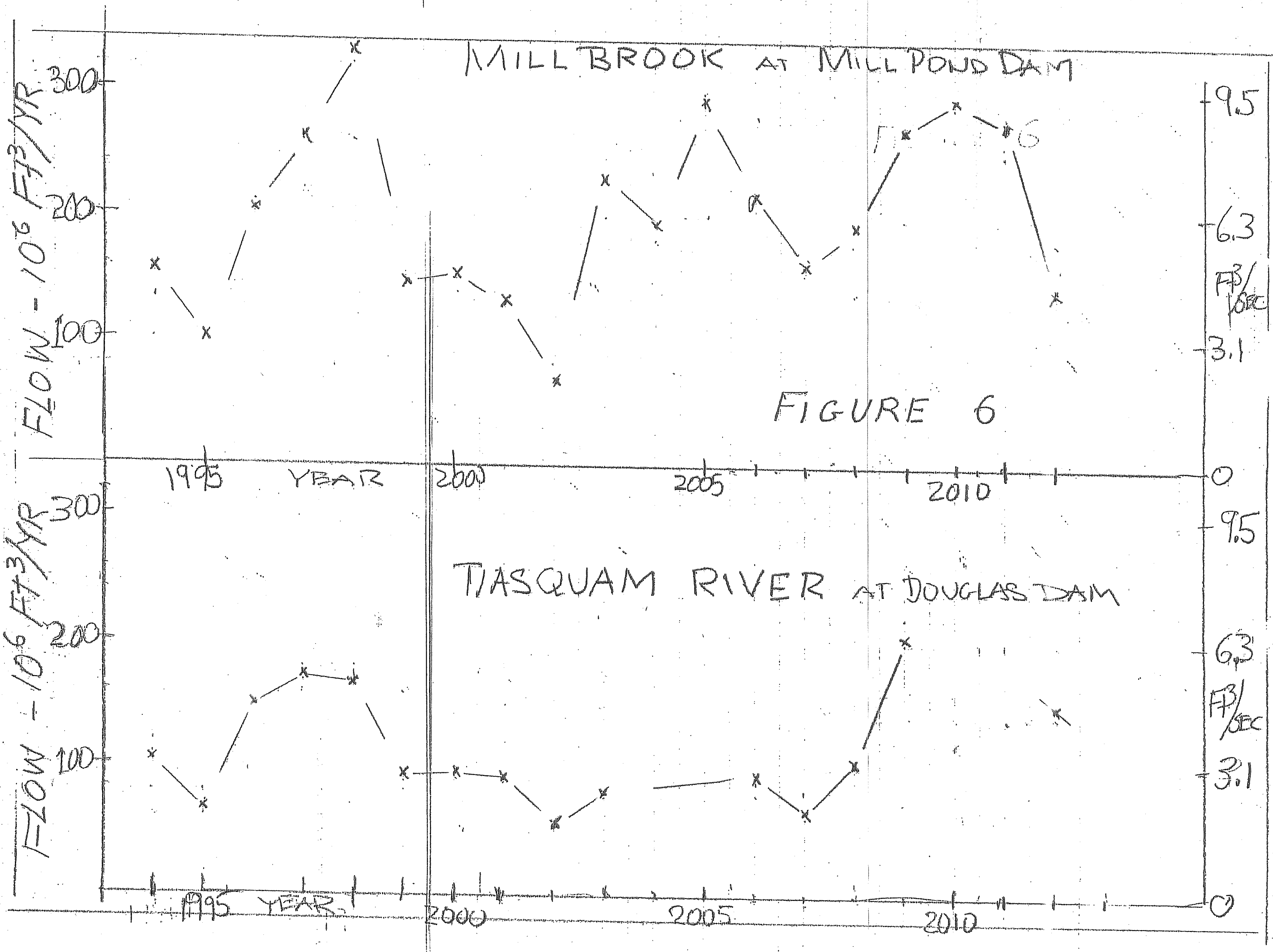



TOTAL FLOW OVER DAM FROM 1.8 INCHES OF RAIN

$\frac{1}{2} \times 18.25\ \frac{\text{FT}^3}{\text{SEC}} \times 44\ \text{HR} \times 3600\ \frac{\text{SEC}}{\text{HR}}$

$= \underline{1.44 \times 10^6\ \text{FT}^3}$

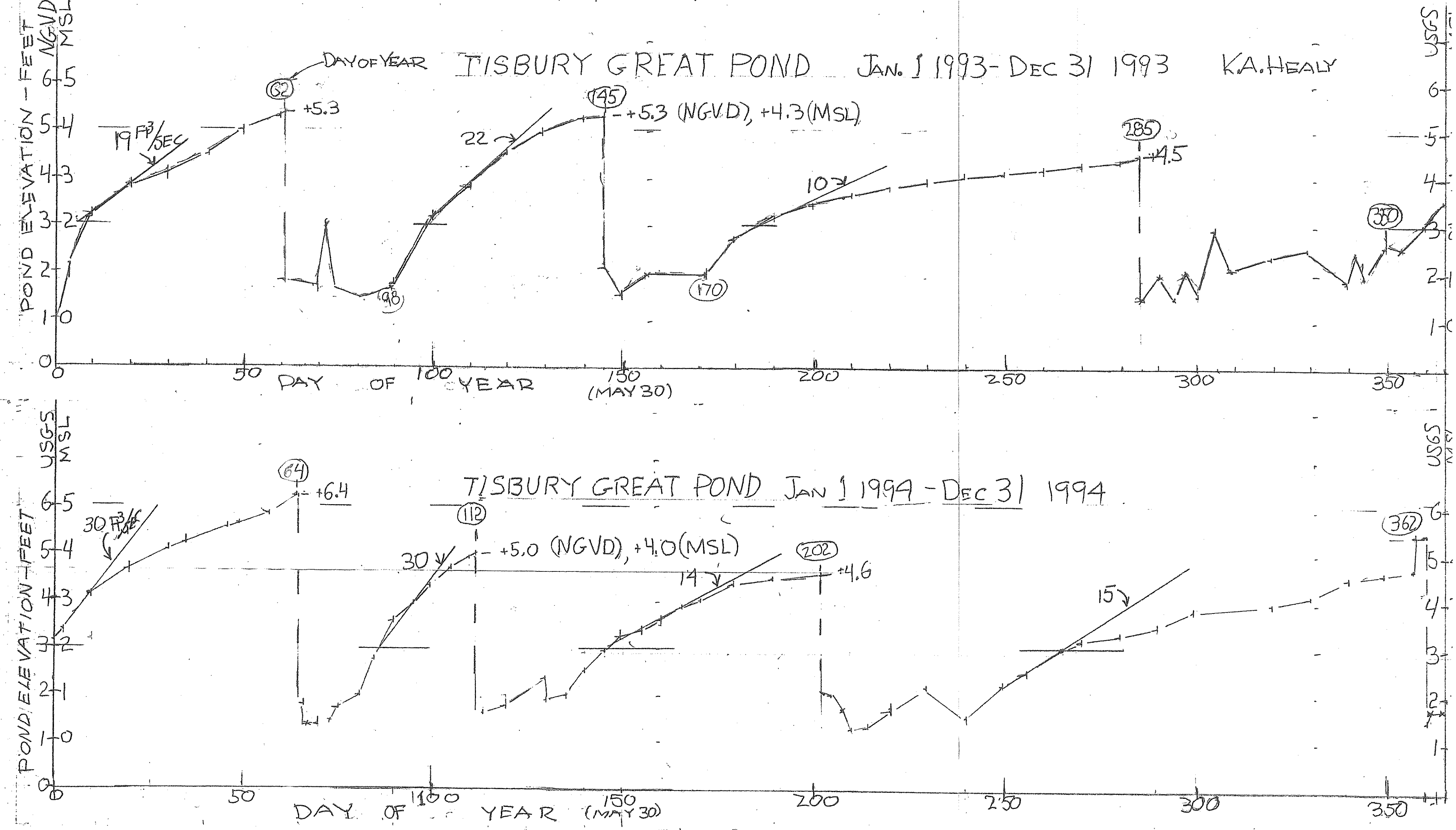
$\frac{1.44}{19.08} = 0.07$



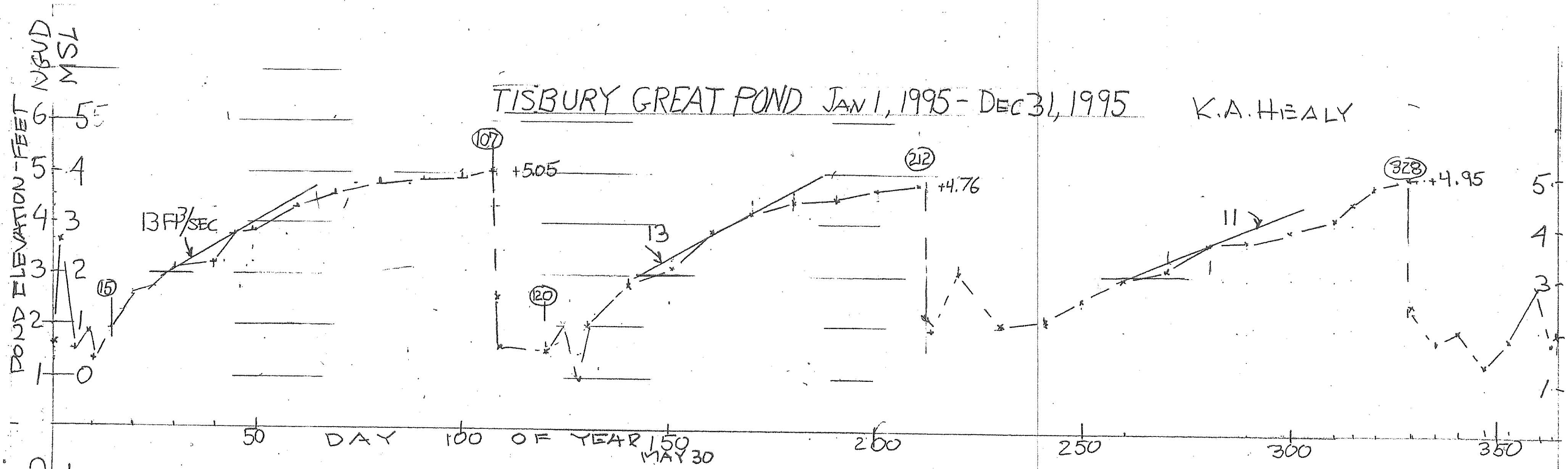
MILLBROOK AT MILL POND DAM
FLOW - $10^6$ FT$^3$/YR
300
200
100
9.5
6.3
FT$^3$/SEC
3.1
0
1995
YEAR
2000
2005
2010
TIASQUAM RIVER AT DOUGLAS DAM
FLOW - $10^6$ FT$^3$/YR
300
200
100
9.5
6.3
FT$^3$/SEC
3.1
0
1995
YEAR
2000
2005
2010

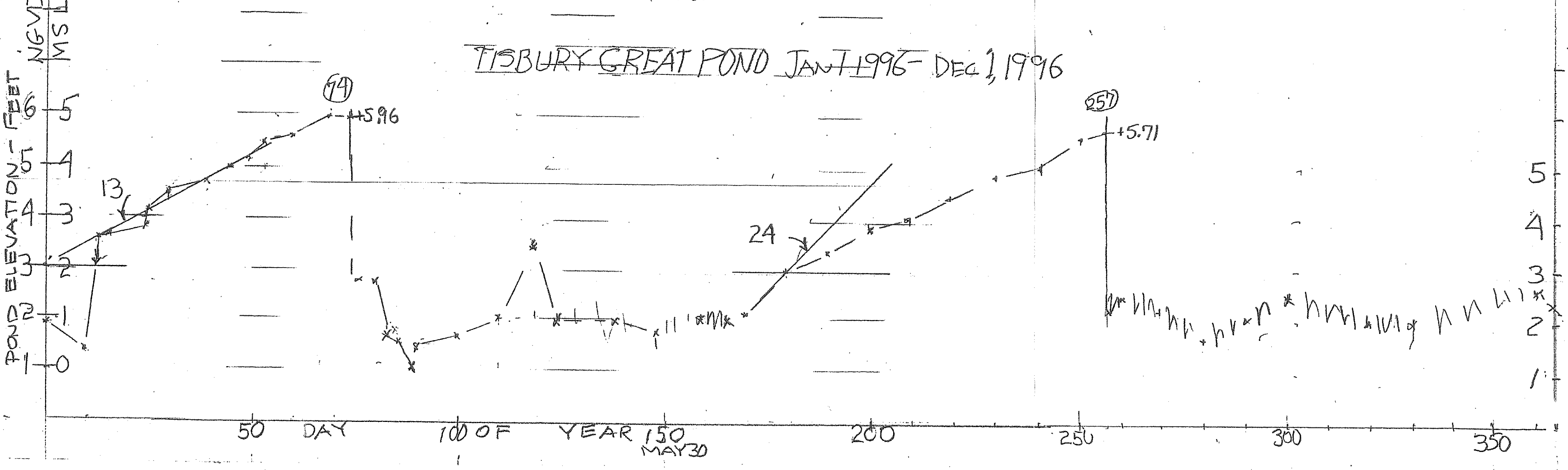

FIGURE 6

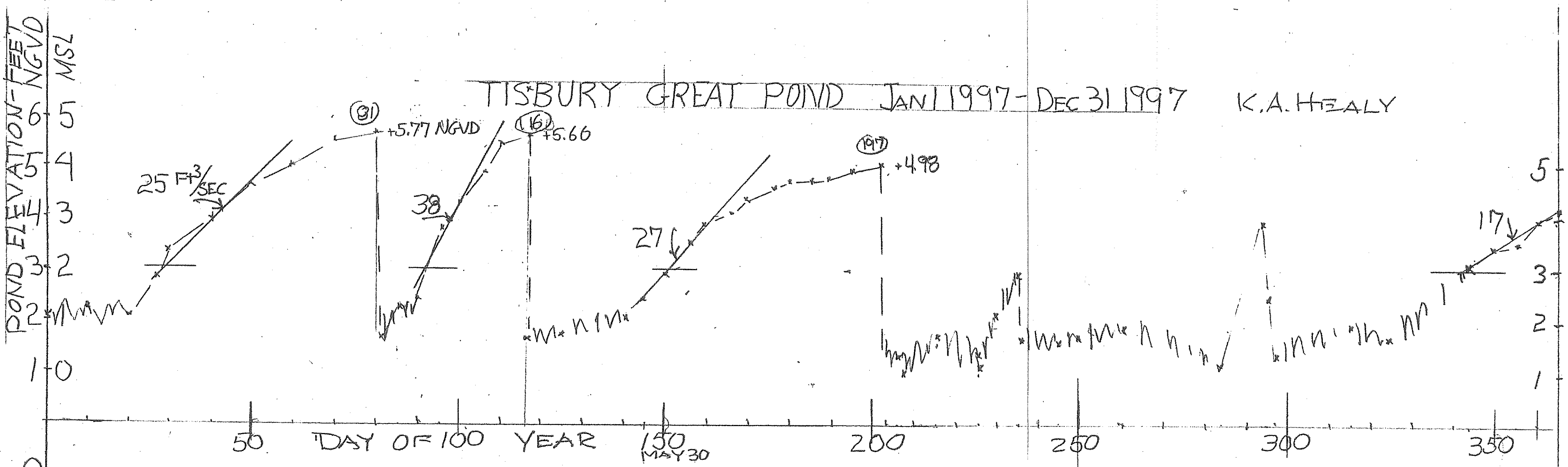
FIG. 7

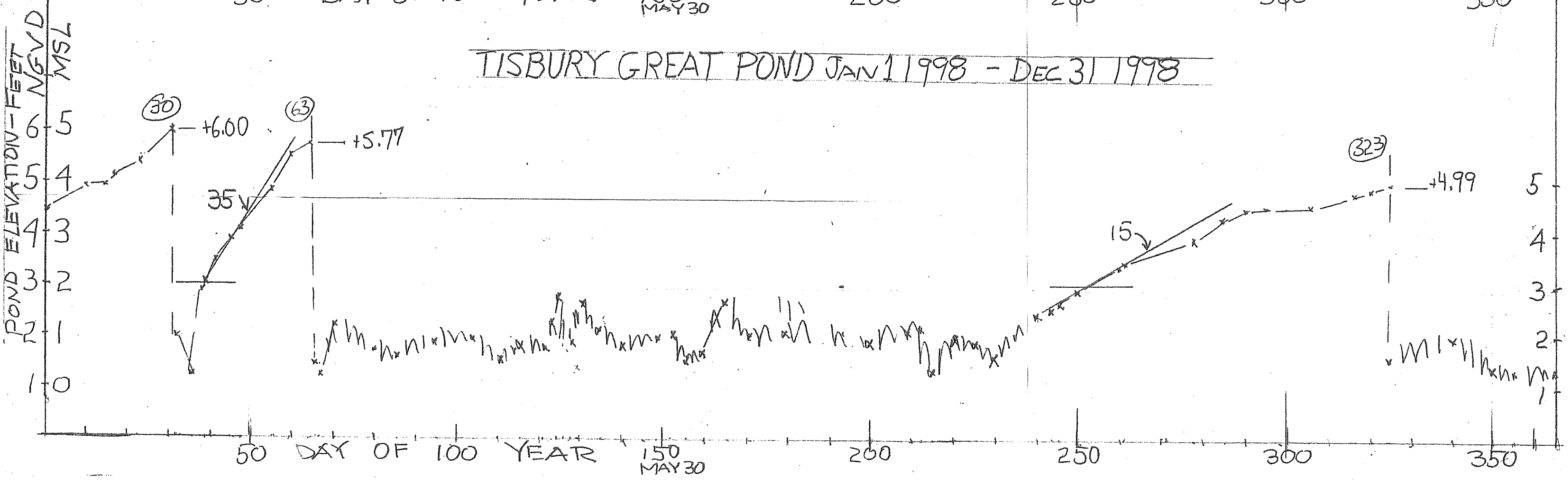


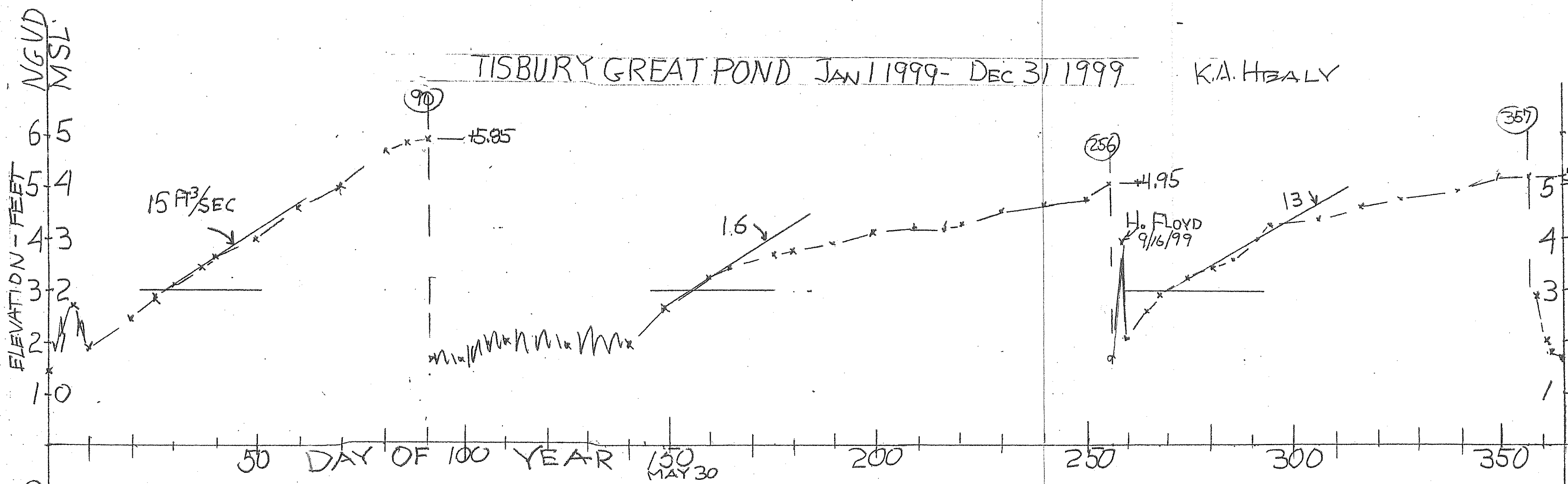
TISBURY GREAT POND JAN. 1 1993 - DEC 31 1993
K.A. HEALY
DAY OF YEAR
POND ELEVATION - FEET
NGVD
MSL
USGS
62
+5.3
19 FT³/SEC
98
22
145
+5.3 (NGVD), +4.3 (MSL)
170
10
285
+4.5
350
DAY OF YEAR
150 (MAY 30)
TISBURY GREAT POND JAN 1 1994 - DEC 31 1994
POND ELEVATION - FEET
USGS
MSL
64
+6.4
30 FT³/SEC
112
30
+5.0 (NGVD), +4.0 (MSL)
14
202
+4.6
15
362
DAY OF YEAR
150 (MAY 30)

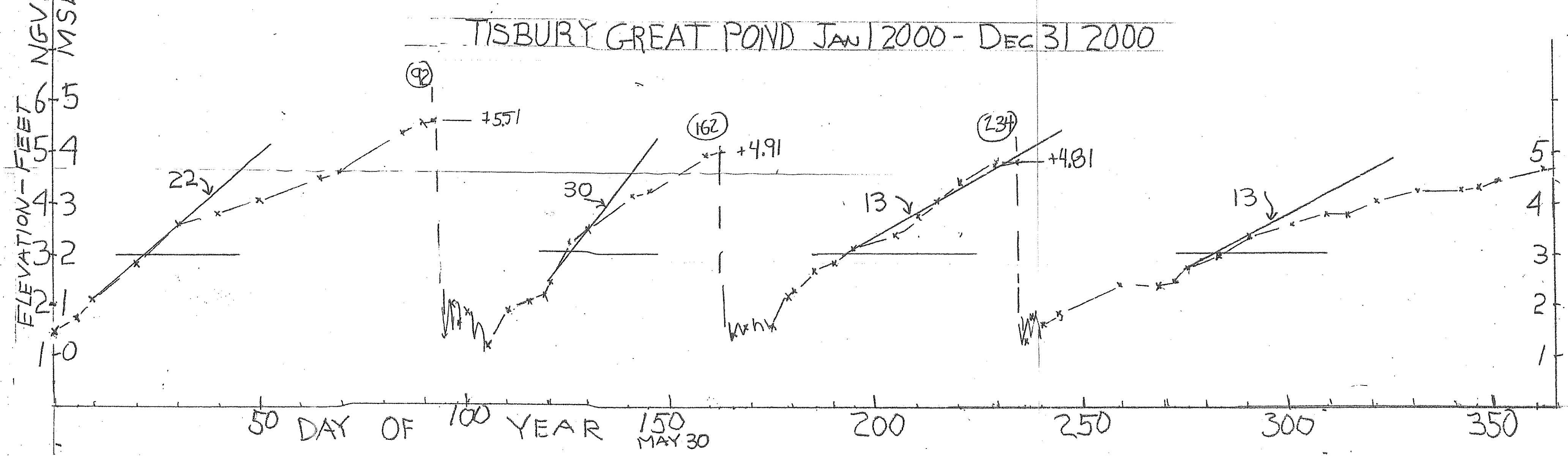

TISBURY GREAT POND JAN 1, 1995 - DEC 31, 1995
K.A. HEALY
POND ELEVATION - FEET
NGVD
MSL
13 FT3/SEC
13
11
15
107
120
212
328
+5.05
+4.76
+4.95
DAY OF YEAR
MAY 30
50
100
150
200
250
300
350


TISBURY GREAT POND JAN 1 1996 - DEC 1, 1996
POND ELEVATION - FEET
NGVD
MSL
13
24
74
257
+5.96
+5.71
DAY OF YEAR
MAY 30
50
100
150
200
250
300
350

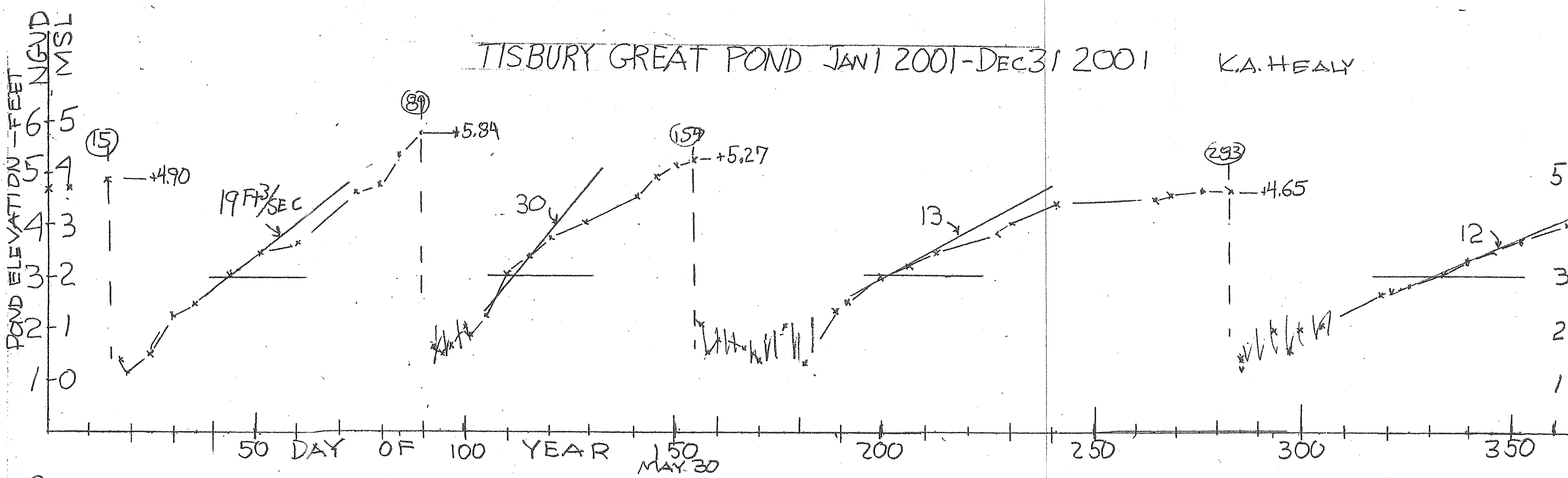

TISBURY GREAT POND JAN 1 1997 - DEC 31 1997
K.A. HEALY
POND ELEVATION - FEET
NGVD
MSL
25 FT³/SEC
38
27
17
(31) +5.77 NGVD
(161) +5.66
(197) +4.98
DAY OF 100 YEAR
150
MAY 30


TISBURY GREAT POND JAN 1 1998 - DEC 31 1998
POND ELEVATION - FEET
NGVD
MSL
(30) +6.00
(63) +5.77
(323) +4.99
35
15
DAY OF 100 YEAR
150
MAY 30

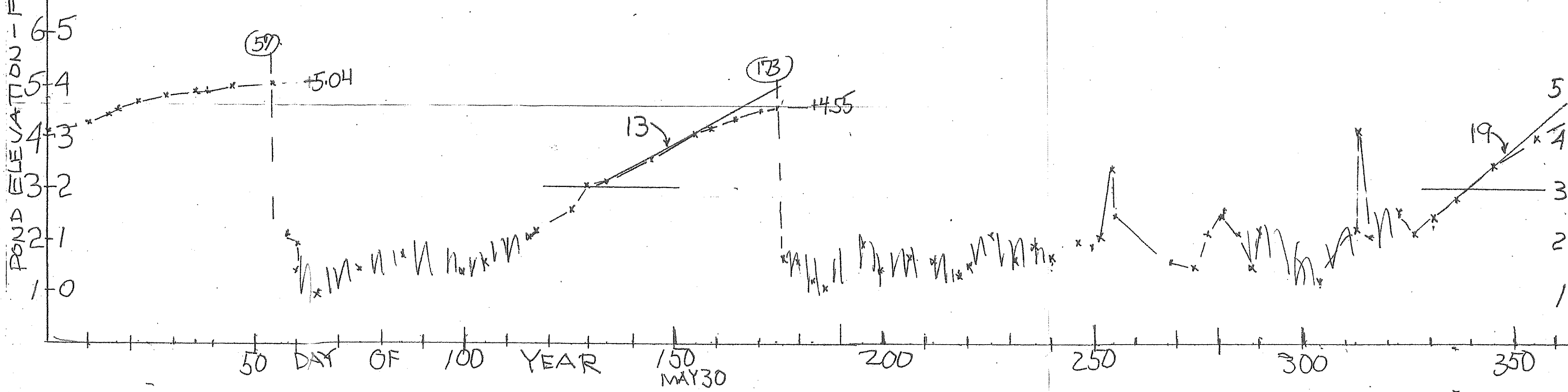

TISBURY GREAT POND JAN 1 1999 - DEC 31 1999
K.A. HEALY
ELEVATION - FEET
NGVD
MSL
90
+5.85
15 FT³/SEC
1.6
256
+4.95
H. FLOYD 9/16/99
13
357
DAY OF YEAR
150 MAY 30


TISBURY GREAT POND JAN 1 2000 - DEC 31 2000
ELEVATION - FEET
NGVD
MSL
92
+5.51
22
30
162
+4.91
13
234
+4.81
13
DAY OF YEAR
150 MAY 30

TISBURY GREAT POND JAN 1 2001-DEC 31 2001 K.A. HEALY

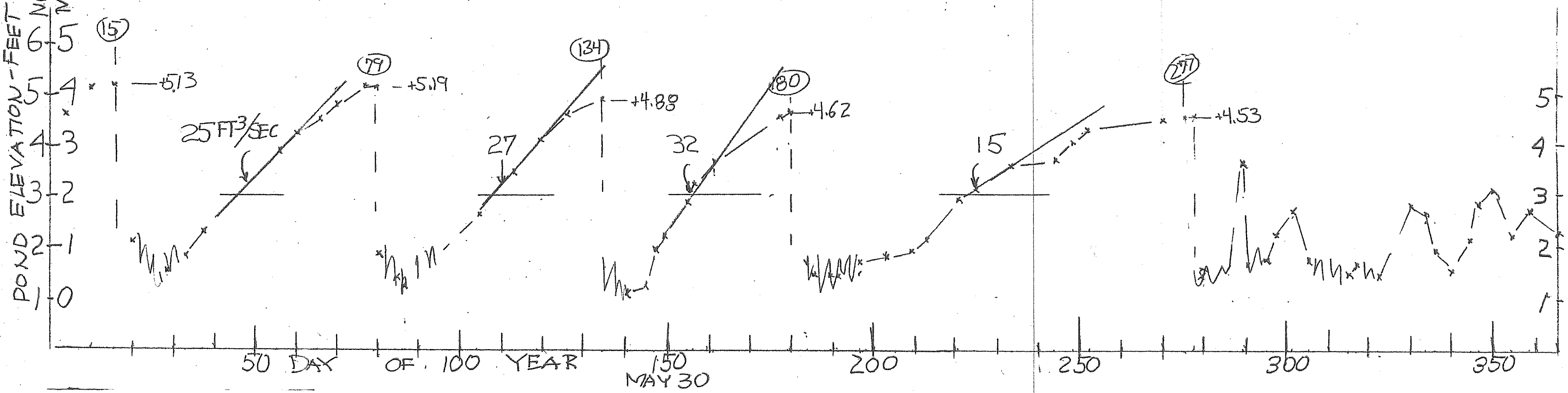



TISBURY GREAT POND JAN 1, 2002 - DEC 31, 2002

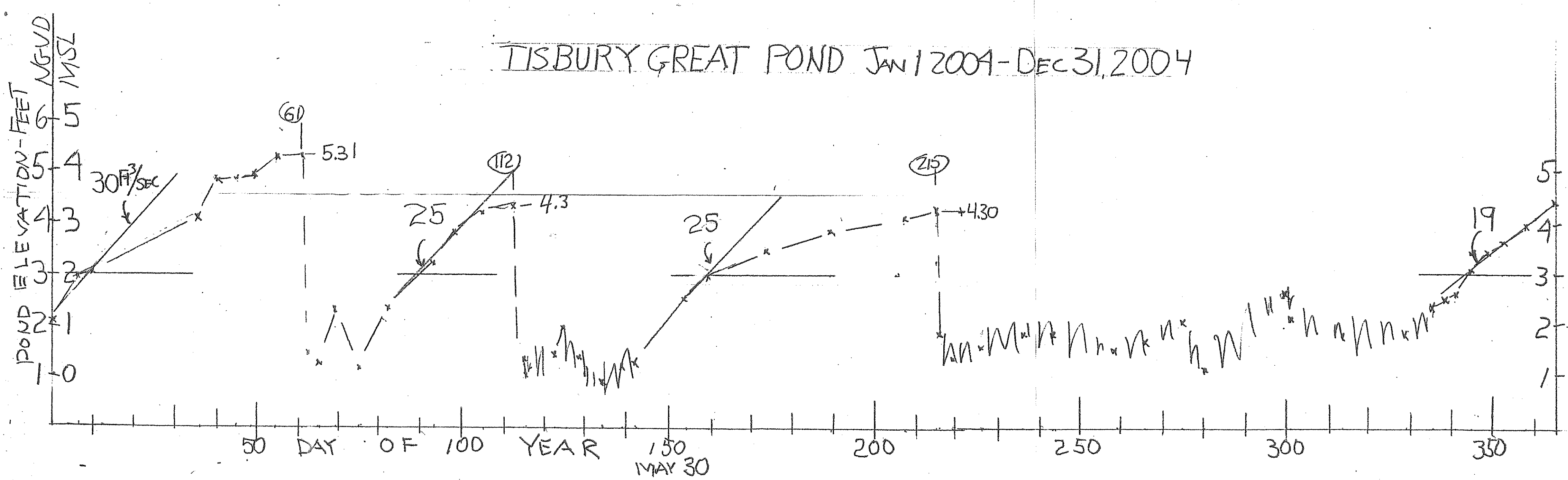


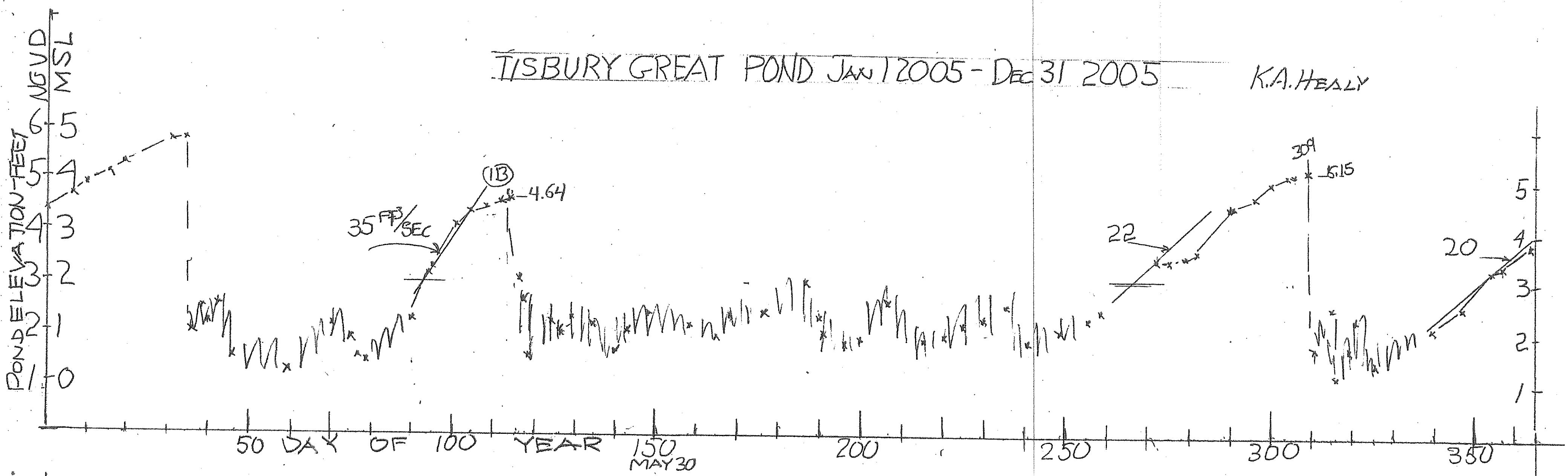
TISBURY GREAT POND JAN 1 2003 - DEC 31 2003

KA HEALY

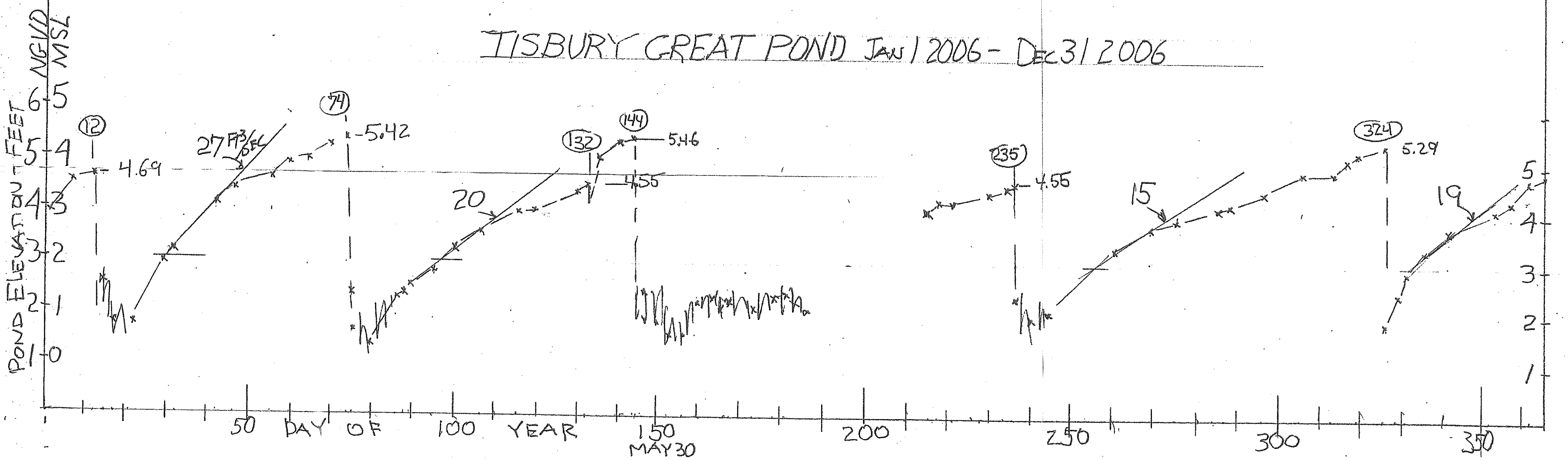



TISBURY GREAT POND JAN 1 2004 - DEC 31, 2004

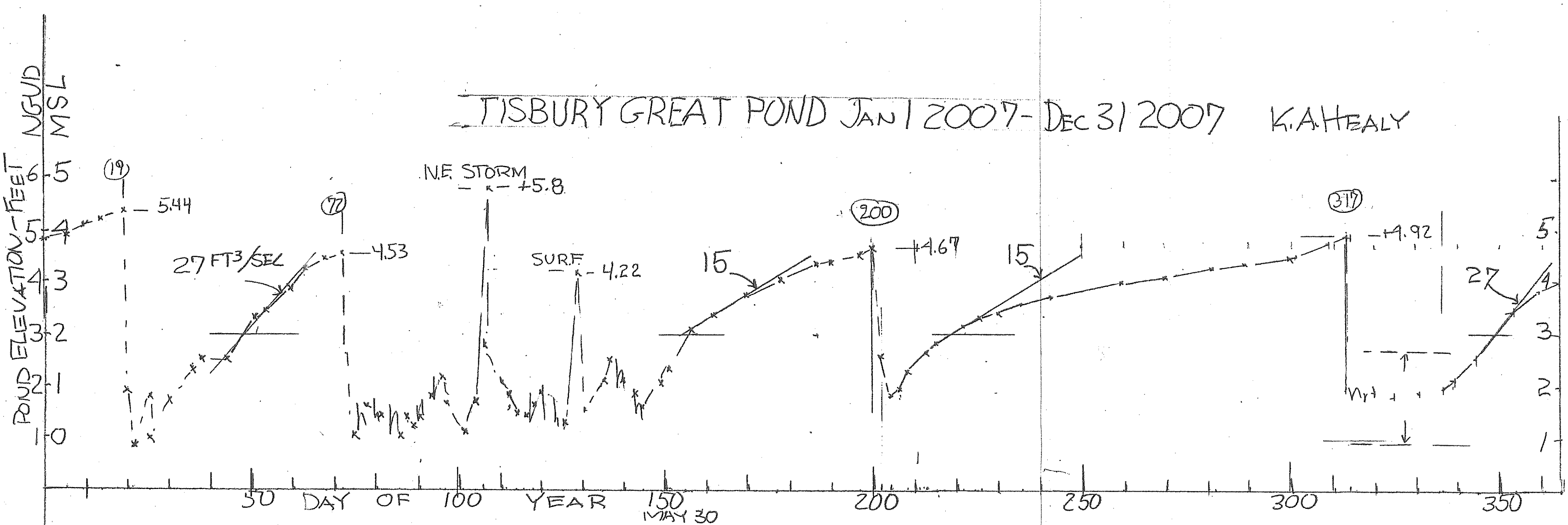


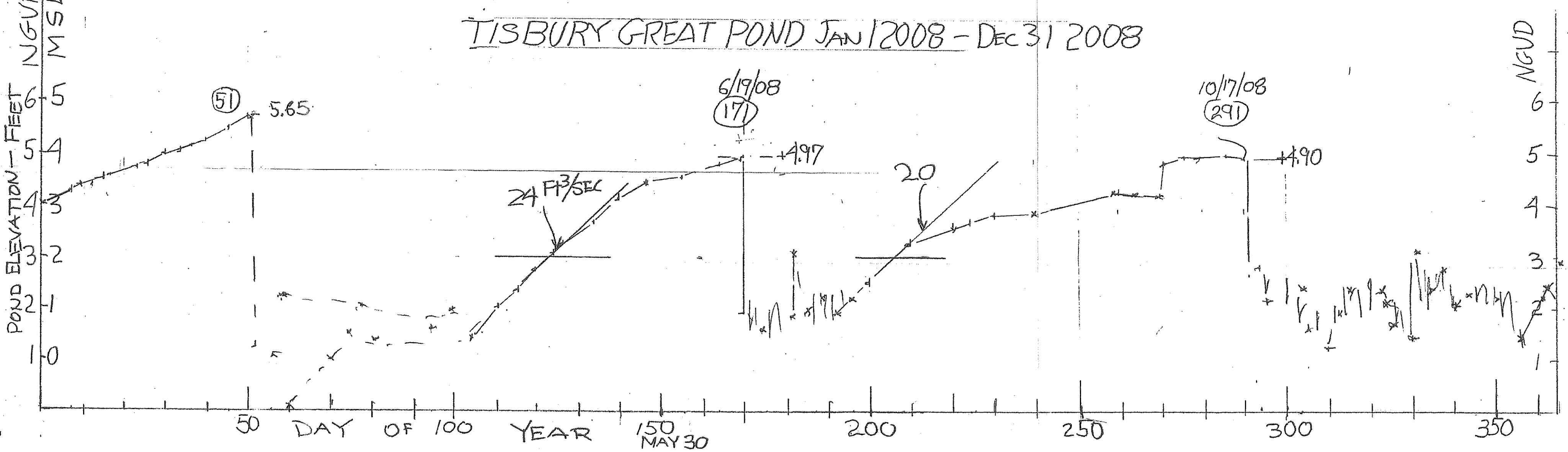


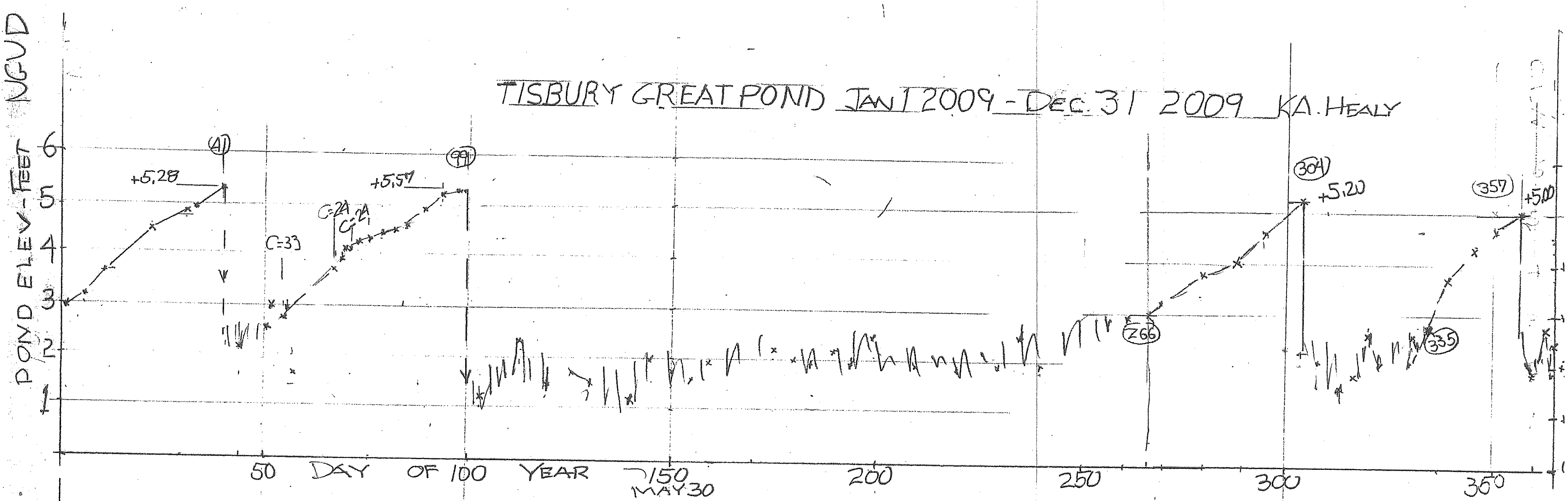
TISBURY GREAT POND JAN 1 2005 - DEC 31 2005
K.A. HEALY
POND ELEVATION-FEET NGVD MSL
35 FT3/SEC
113
4.64
22
309
5.15
20
50 DAY OF 100 YEAR 150 MAY 30 200 250 300 350

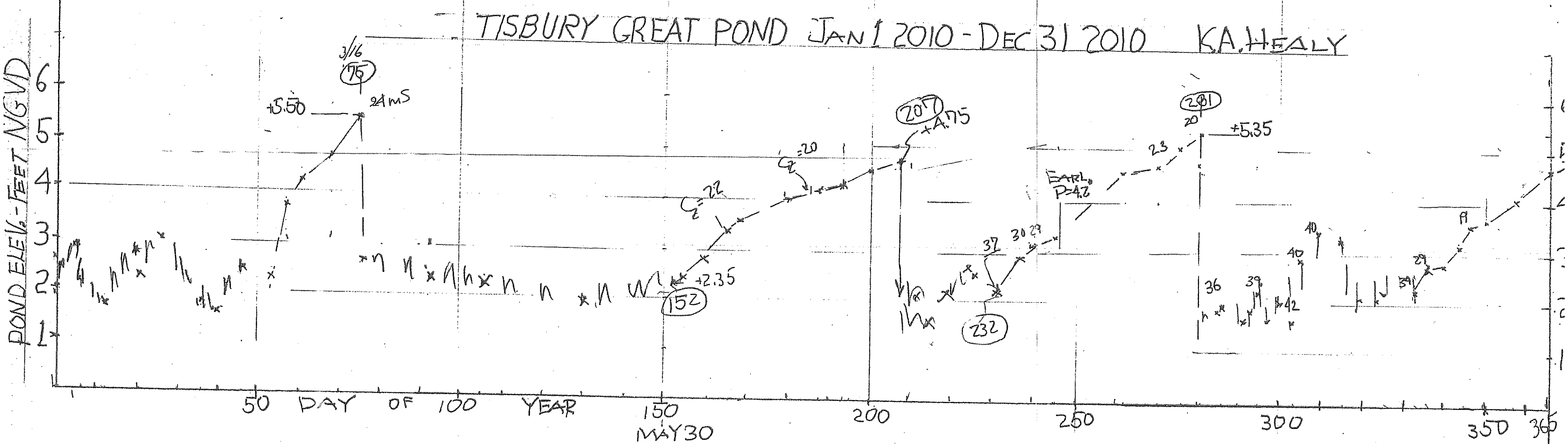



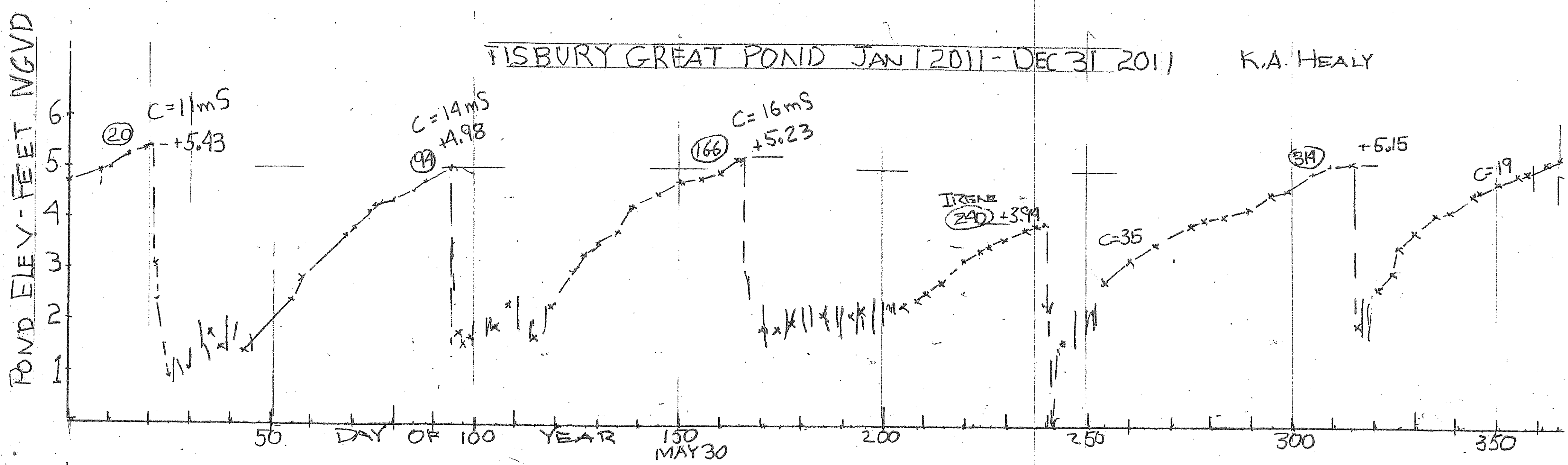
TISBURY GREAT POND JAN 1 2006 - DEC 31 2006
POND ELEVATION FEET NGVD MSL
12
4.69
27 FT3/SEC
74
5.42
20
132
144
5.46
4.55
235
4.55
15
324
5.29
19
50 DAY OF 100 YEAR 150 MAY 30 200 250 300 350


TISBURY GREAT POND JAN 1 2007 - DEC 31 2007
K.A. HEALY
POND ELEVATION - FEET
NGVD
MSL
19
5.44
27 FT³/SEC
72
4.53
N.E. STORM
+5.8
SURF
4.22
15
200
+4.67
15
317
+4.92
27
DAY OF YEAR
MAY 30

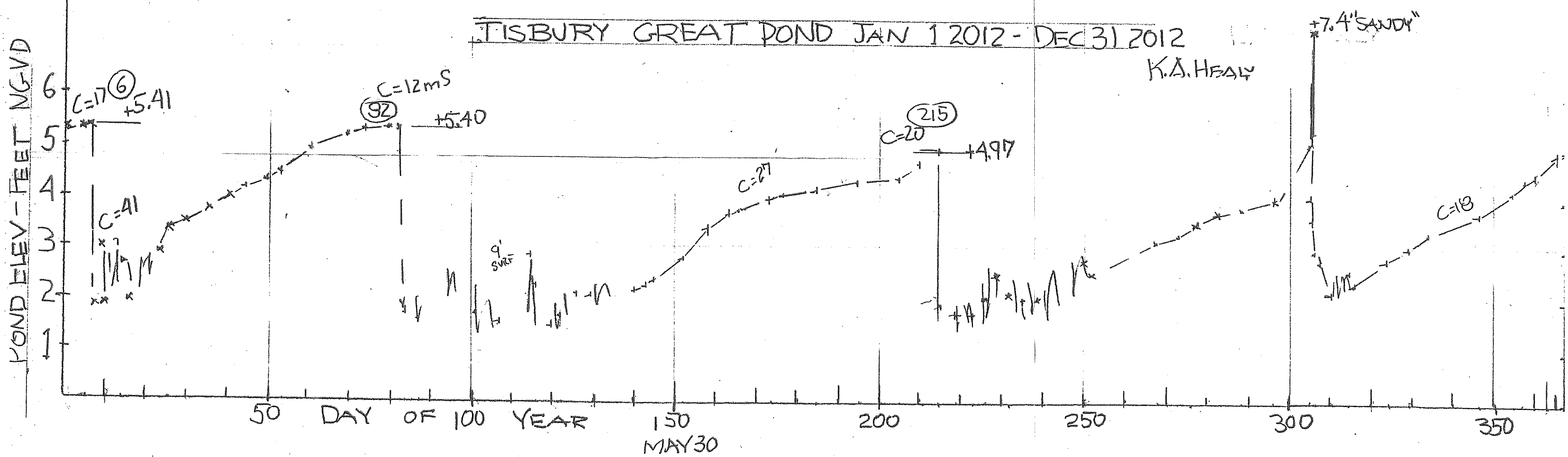

TISBURY GREAT POND JAN 1 2008 - DEC 31 2008
POND ELEVATION - FEET
NGVD
MSL
51
5.65
24 FT³/SEC
6/19/08
171
+4.97
20
10/17/08
291
+4.90
NGVD
DAY OF YEAR
MAY 30


TISBURY GREAT POND JAN 1 2009 - DEC 31 2009 K.A. HEALY
POND ELEV - FEET NGVD
DAY OF YEAR
MAY 30
41
+5.28
C=33
C=24
C=24
+5.57
99
266
304
+5.20
335
357
+5.00

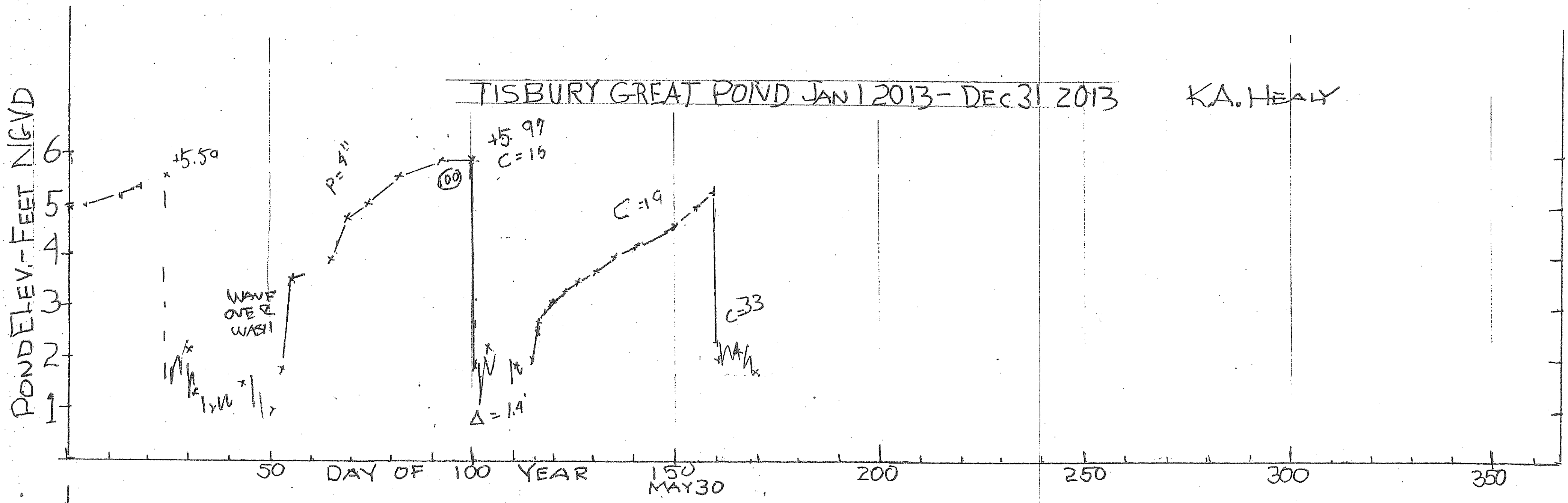

TISBURY GREAT POND JAN 1 2010 - DEC 31 2010 K.A. HEALY
POND ELEV - FEET NGVD
DAY OF YEAR
MAY 30
3/16
75
+5.50
24 MS
152
+2.35
207
+4.75
232
EARL
P=4.2
281
+5.35



TISBURY GREAT POND JAN 1 2011 - DEC 31 2011
K.A. HEALY
POND ELEV - FEET NGVD
C=11mS
20
+5.43
C=14mS
99
+4.98
C=16mS
166
+5.23
IRENE
240
+3.94
C=35
314
+5.15
C=19
DAY OF YEAR
50
100
150
MAY 30
200
250
300
350

TISBURY GREAT POND JAN 1 2012 - DEC 31 2012
K.A. HEALY
POND ELEV - FEET NGVD
C=17
6
+5.41
C=41
C=12mS
92
+5.40
9' SURF
C=27
C=20
215
+4.97
+7.4' "SANDY"
C=18
DAY OF YEAR
50
100
150
MAY 30
200
250
300
350


TISBURY GREAT POND JAN 1 2013 - DEC 31 2013
K.A. HEALY
POND ELEV. - FEET NGVD
6
5
4
3
2
1
+5.59
P = 4"
100
+5.97
C = 15
C = 19
WAVE OVER WASH
C = 33
Δ = 1.4'
50
DAY OF
100
YEAR
150
MAY 30
200
250
300
350

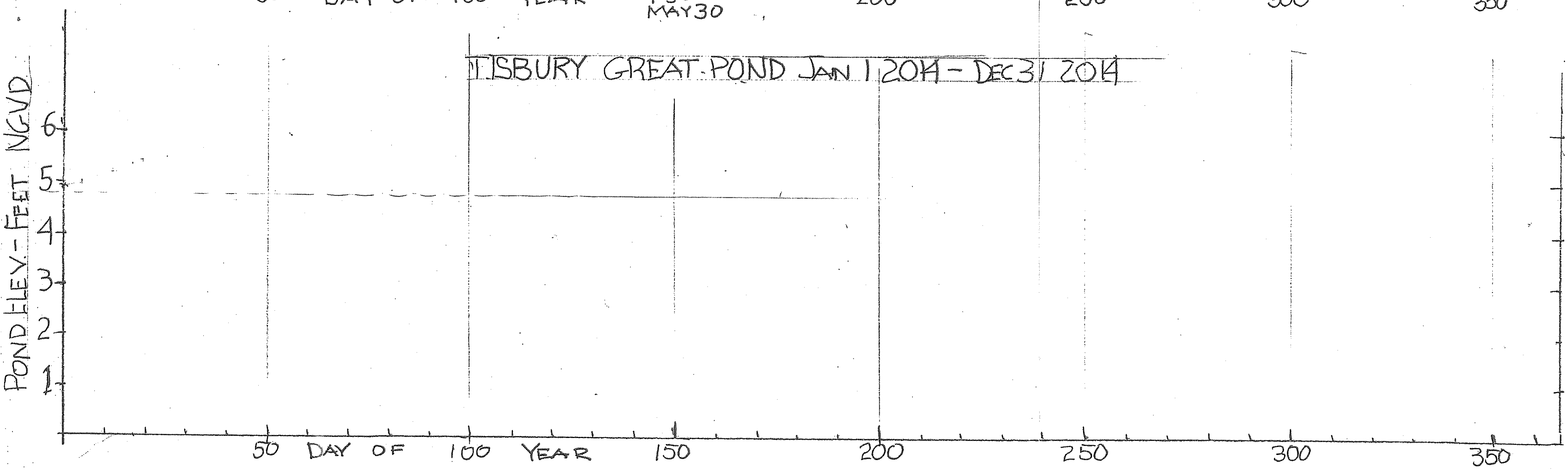

TISBURY GREAT POND JAN 1 2014 - DEC 31 2014
POND ELEV. - FEET NGVD
6
5
4
3
2
1
50
DAY OF
100
YEAR
150
200
250
300
350

FIGURE 8

ELEVATION OF POND AFTER CHANNEL CUT MAY 24, 2006

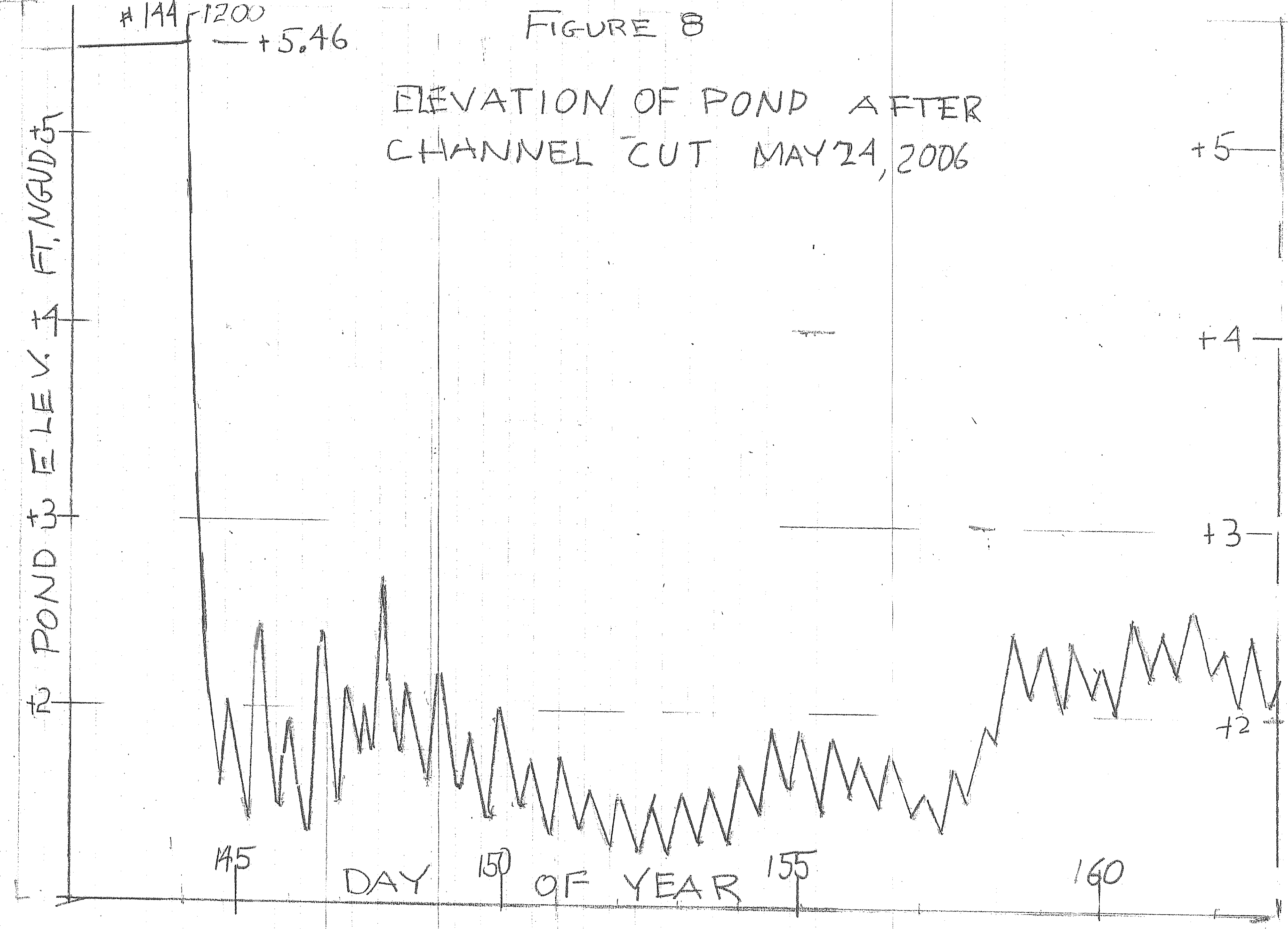


FIG. 9

ELEV. OF GROUNDWATER TABLE @ #122

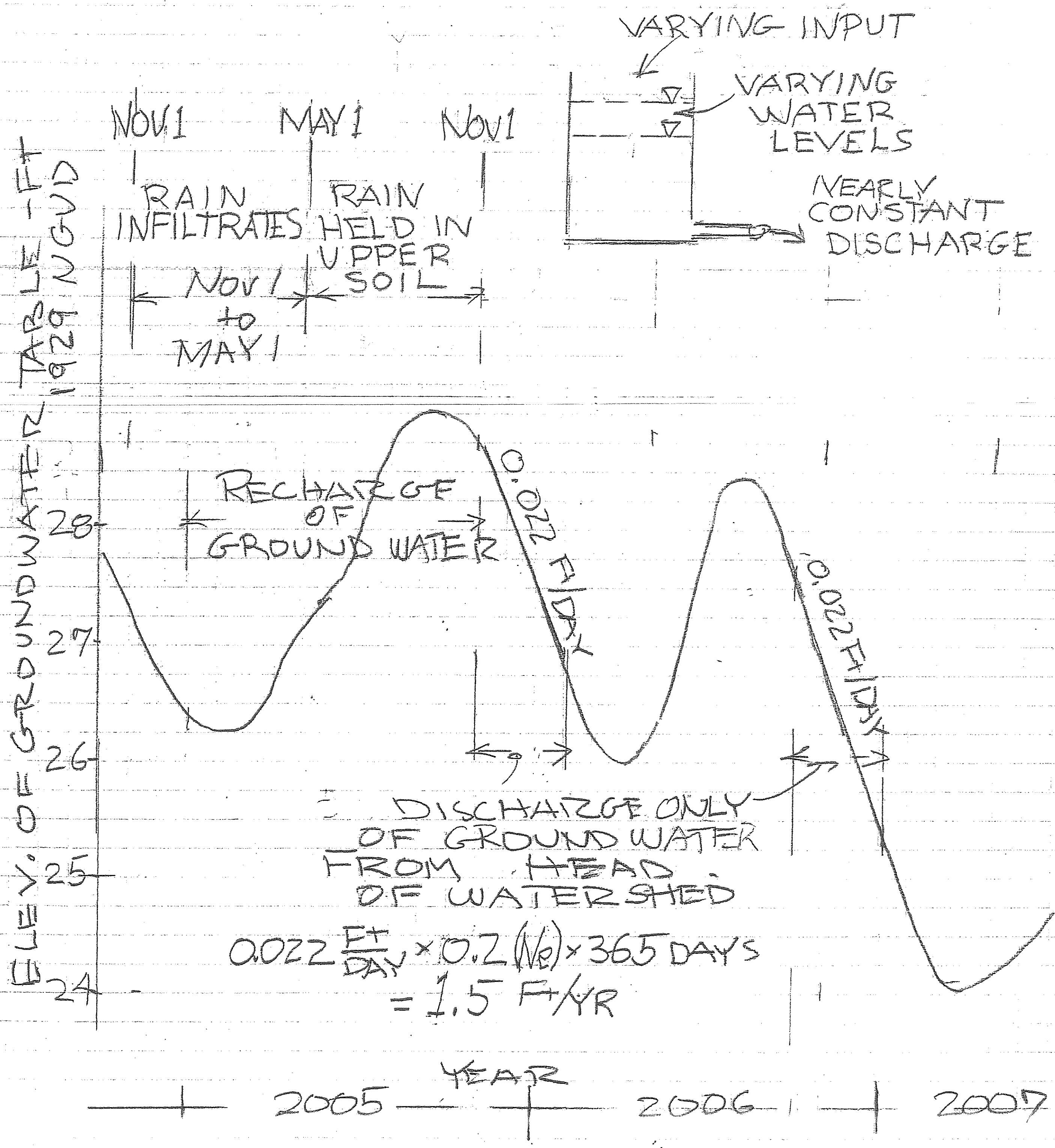
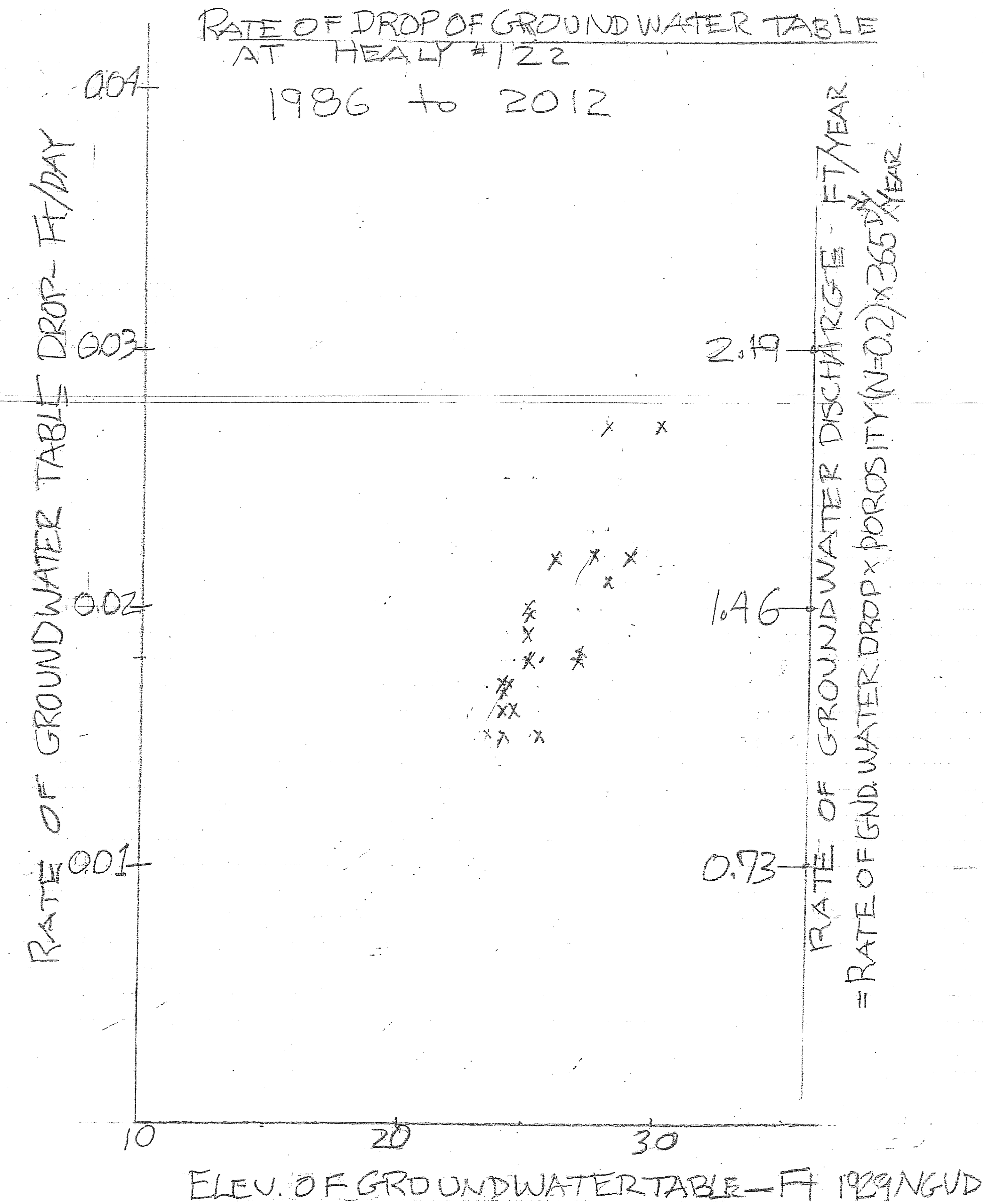


FIG. 10

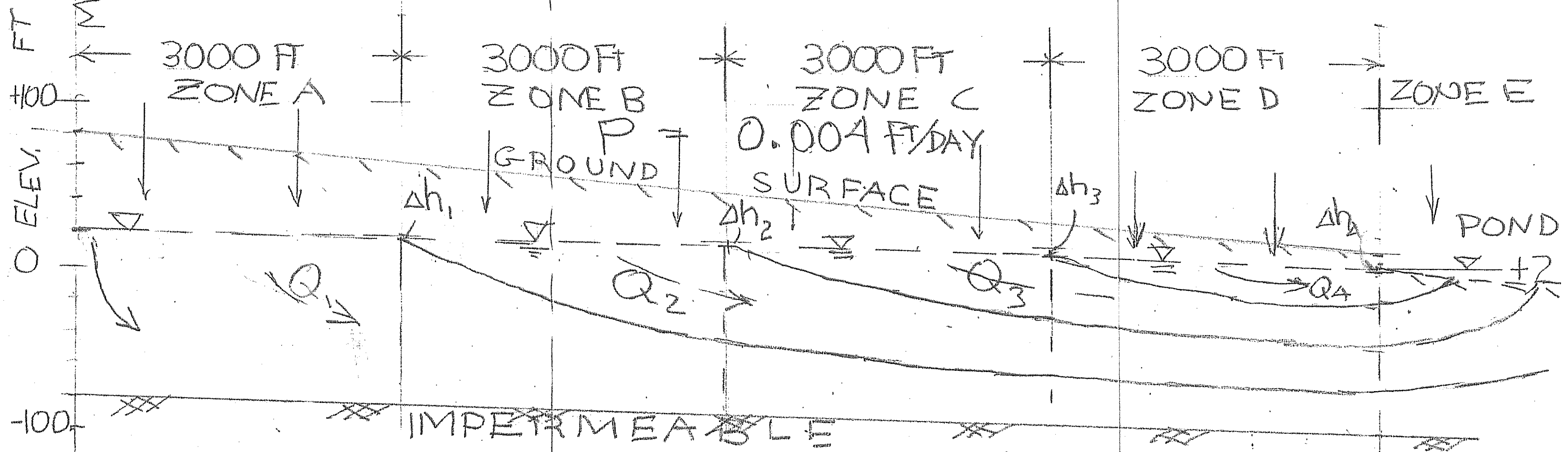


RATE OF DROP OF GROUNDWATER TABLE
AT HEALY #122
1986 to 2012
0.04
0.03
0.02
0.01
2.19
1.46
0.73
RATE OF GROUNDWATER TABLE DROP - FT/DAY
RATE OF GROUNDWATER DISCHARGE - FT/YEAR
= RATE OF GND. WATER DROP x POROSITY (N=0.2) x 365 DAY/YEAR
10
20
30
ELEV. OF GROUNDWATER TABLE - FT 1929 NGVD

Figure 11

**IDEALIZED FLOWNET IN ONE FOOT WIDE, 12,000 FOOT LONG OF 100 FOOT THICK SAND FROM MVC #8 TO TOWN COVE** AND #122

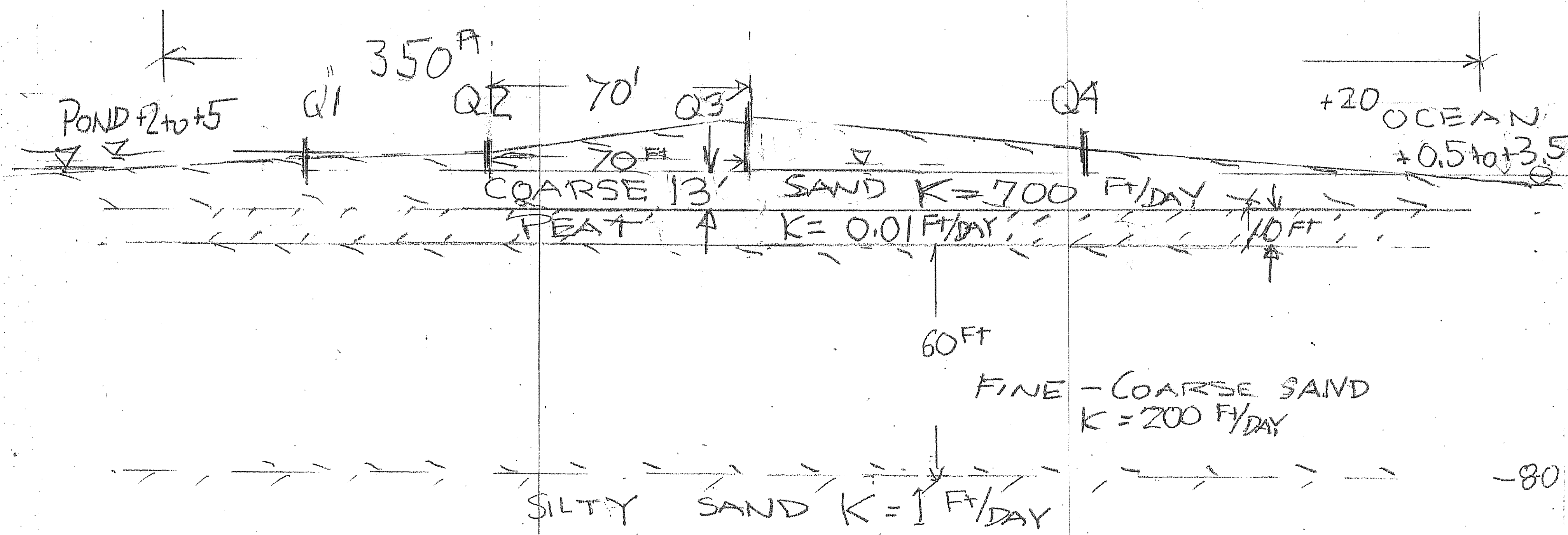
Avg. Recharge of 1.5 feet/ 365 days: Four Flow Tubes with equal Flow:
Flow /tube = 3000 ft2 x 1.5 ft/365 days = 12.3 ft3/day/tube; Uniform k, Uniform N=0.25




| ZONE | Q-Ft³/DAY | L/A | ΔhK = QL/A | Δh = QL/AK | TRAVEL TIME = $L/V_{SEEP} = L^2N/K\Delta h$ |
|---|---|---|---|---|---|
| A | 12.3 | 2000/100 = 20 | 246 | 1.2 - Ft | 4170 DAYS |
| B | 24.7 | 3000/100 = 30 | 740 | 3.7 | 3040 |
| C | 37.0 | 3000/100 = 30 | 1109 | 5.5 | 2040 |
| D | 49.3 | 3000/100 = 30 | 1479 | 7.4 | 1520 |
| E | 49.3 | 1000/100 = 10 | 493 | 2.5 | 500 |
| | | 20 FT x K = | 4067 | 20.3 Ft | 11270 DAYS = 31 YEARS |

K = 200 Ft/DAY

FIG. 12 CROSS SECTION OF BARRIER BEACH 1" = 40'

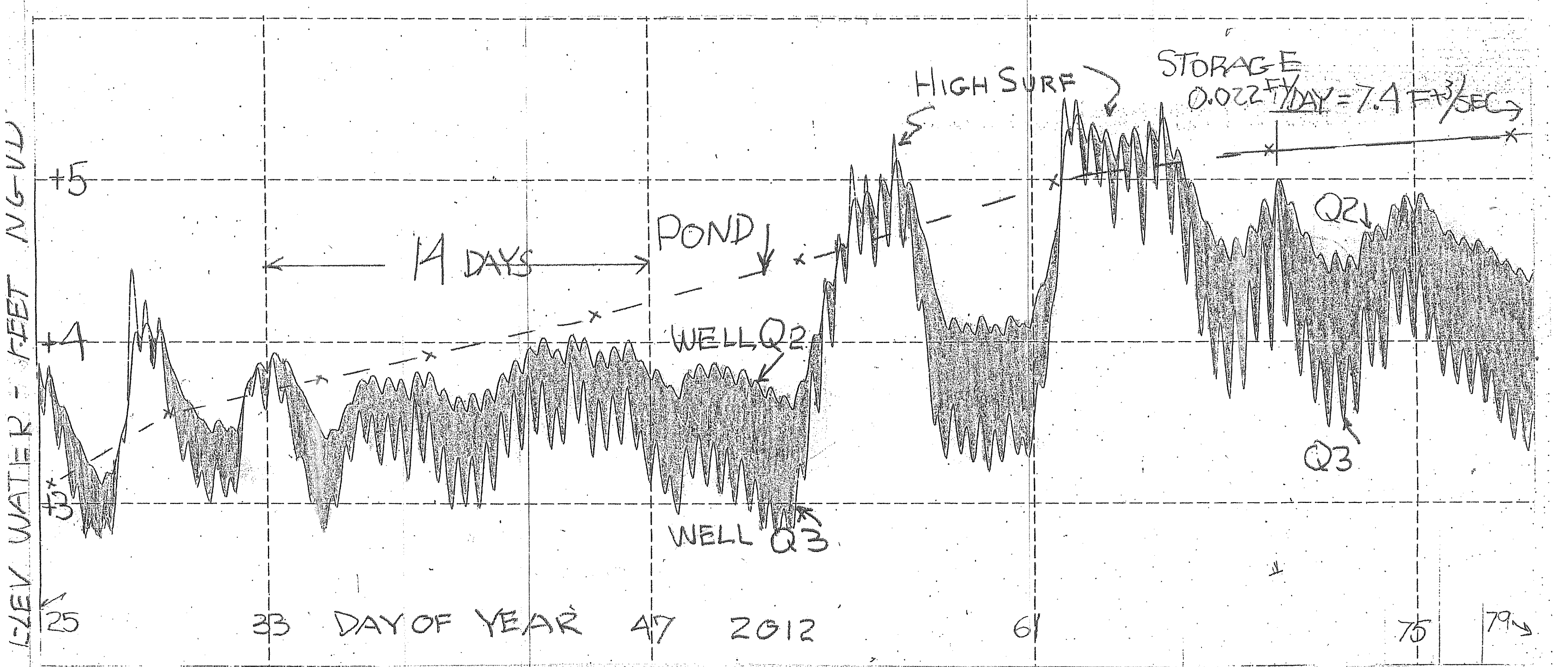



FLOW THROUGH DUNE SAND = KLA

$$= 700\ \mathrm{Ft/DAY} \times \frac{H_{Q2} - H_{Q3}}{70\ \mathrm{Ft}} \times 13\ \mathrm{Ft} \times 9000\ \mathrm{Ft}$$

(LENGTH OF BEACH)

FIG 13 FLOW OUT THROUGH BARRIER BEACH - POND CLOSED

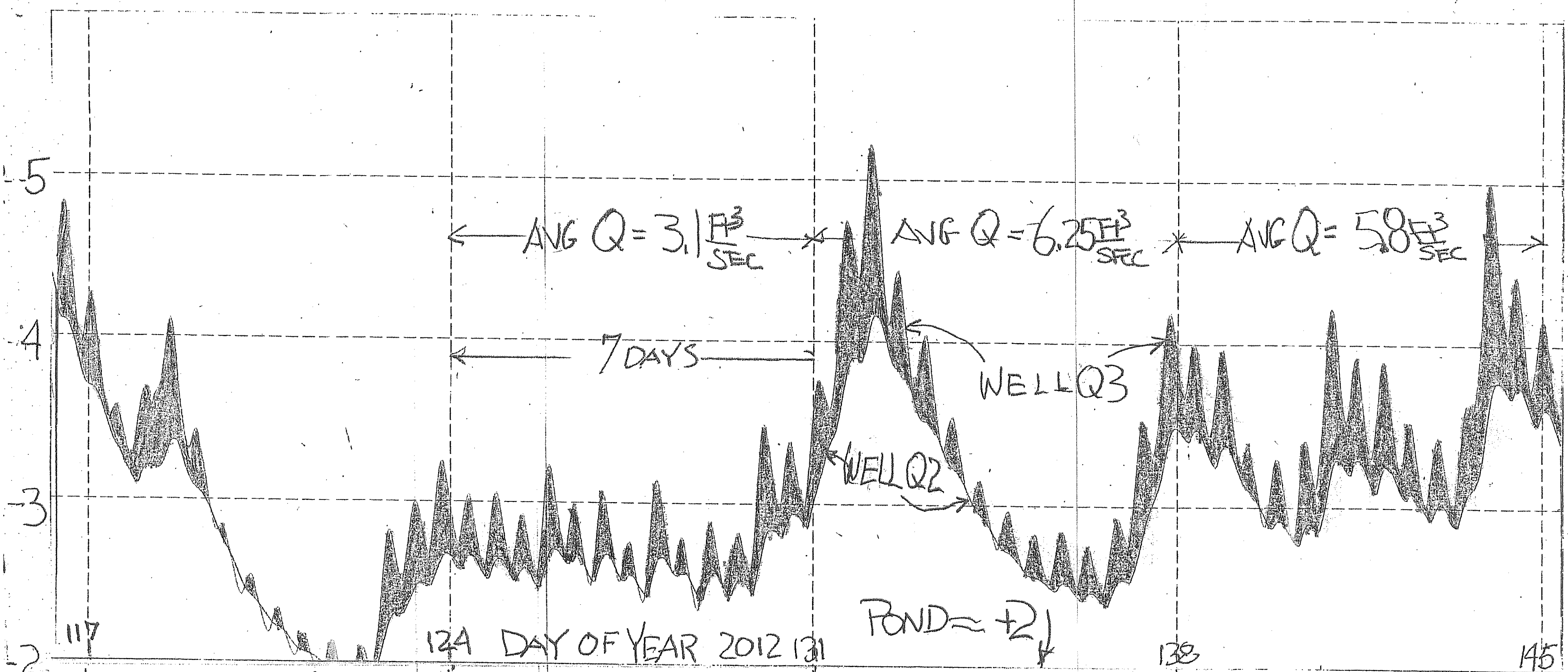



AREA (FT·DAYS) BETWEEN WATER LEVELS REPRESENTS FLOW OUT THROUGH BEACH

$$Q_{\text{DAY 25 TO 79}} = 15.5\ \text{Ft DAYS} \times 9000\ \text{Ft} \times 13\ \text{Ft} \times 700\ \frac{\text{Ft}}{\text{DAY}} \times \frac{1}{70\ \text{Ft}} = 18.4 \times 10^6\ \frac{\text{Ft}^3}{54\ \text{DAYS}}$$

$$= 3.9\ \text{Ft}^3/\text{SEC}$$

FIG. 14 FLOW IN THROUGH BARRIER BEACH - POND OPEN @ +2

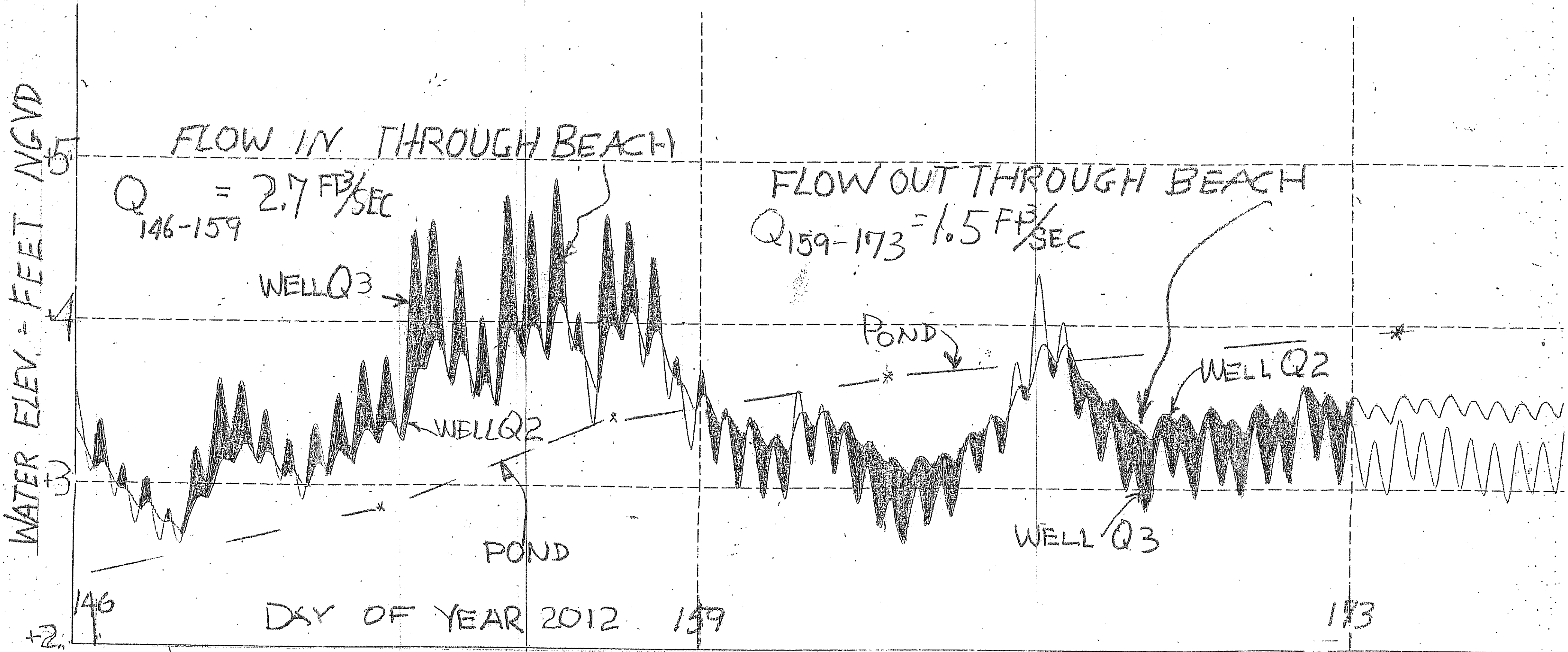



AREA (FT·DAYS) BETWEEN WATER LEVELS REPRESENTS FLOW IN THROUGH BEACH

$$Q_{124\rightarrow145} = 7.9\ \text{FT·DAYS} \times 9000\ \text{FT} \times 13\ \text{FT} \times 700\ \frac{\text{FT}}{\text{DAY}} \times \frac{1}{70\ \text{FT}} = 9.25\times10^{6}\ \text{FT}^3 \text{ IN } 21 \text{ DAYS}$$

$$= 5.1\ \text{FT}^3/\text{SEC}$$

FIG 15 FLOW IN THEN OUT THROUGH BARRIER BEACH AS POND FILLS

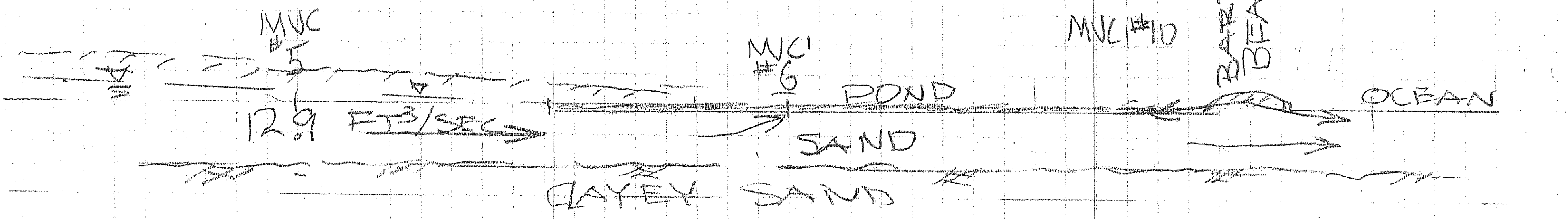



AREA (FT·DAYS) BETWEEN WATER LEVELS IN WELLS REPRESENTS FLOW THROUGH BEACH

KAH 13/2/..

# FIG 16 WATER FLOW INTO POND

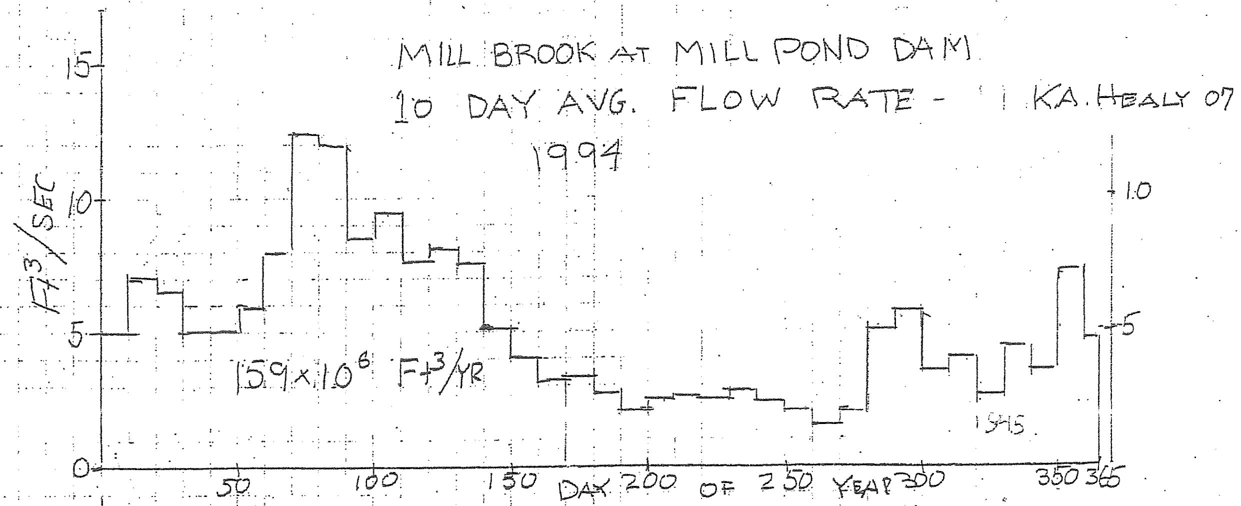
HORIZ. 1" = 2000 Ft VERT 1" = 200 Ft

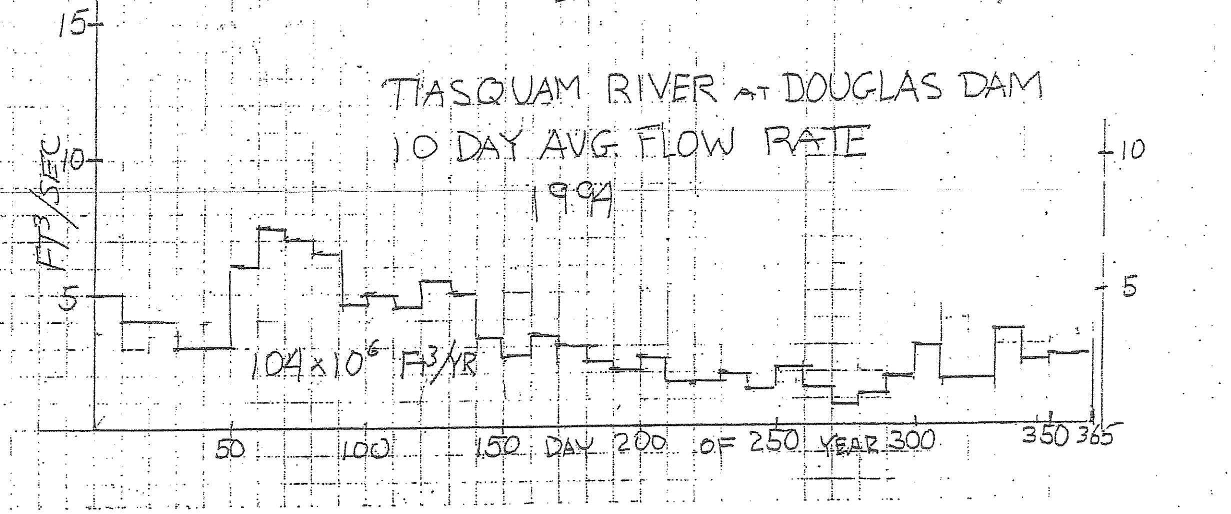


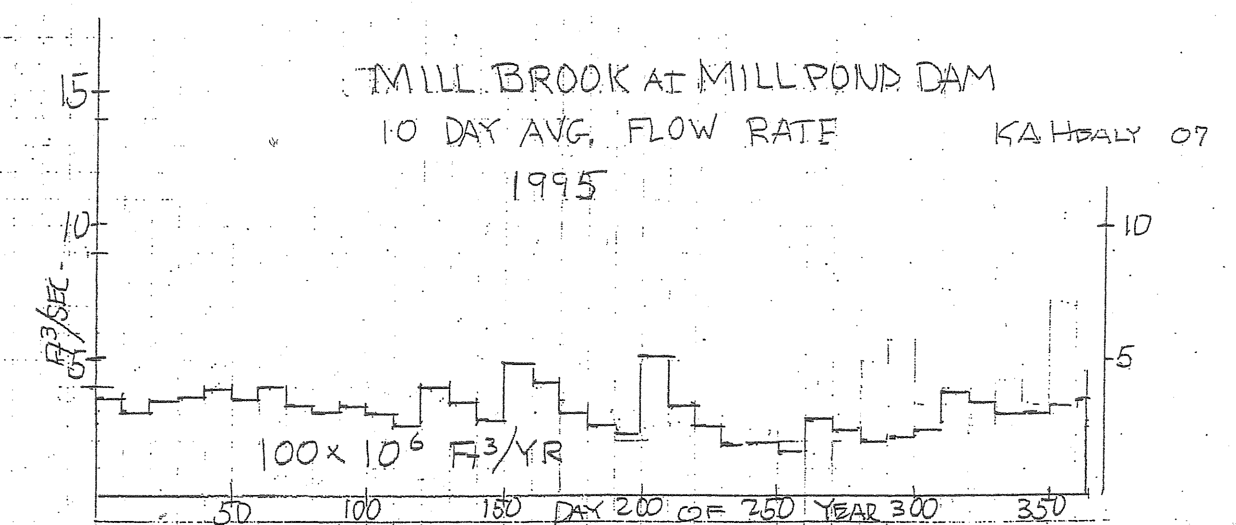

1.5 Ft ANNUAL RECHARGE × 6250 ACRES = 12.9 Ft³/SEC – AREA GROUNDWATER

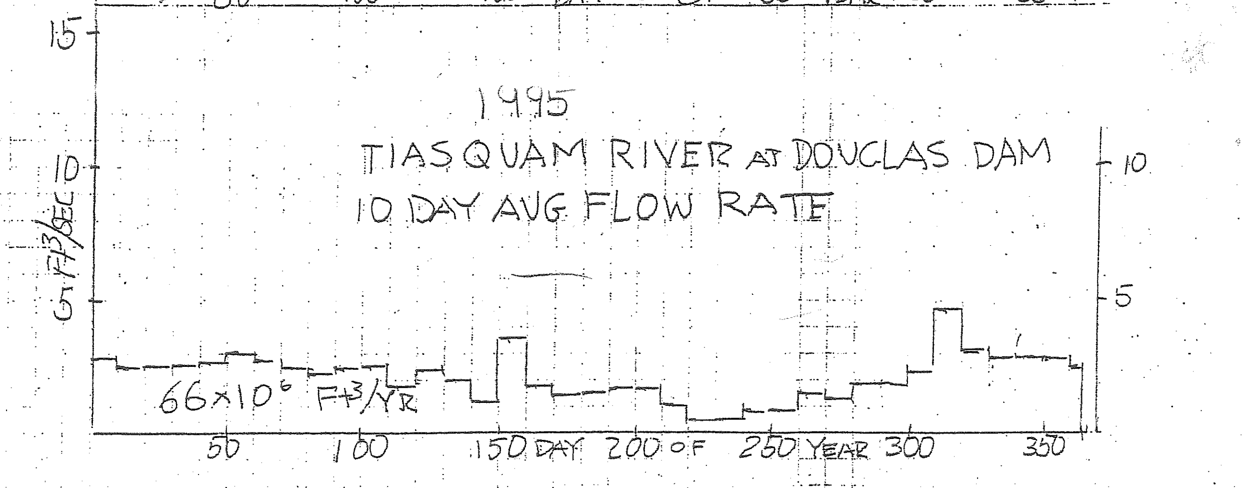
TEN DAY AVERAGE FLOWS – Ft³/SEC

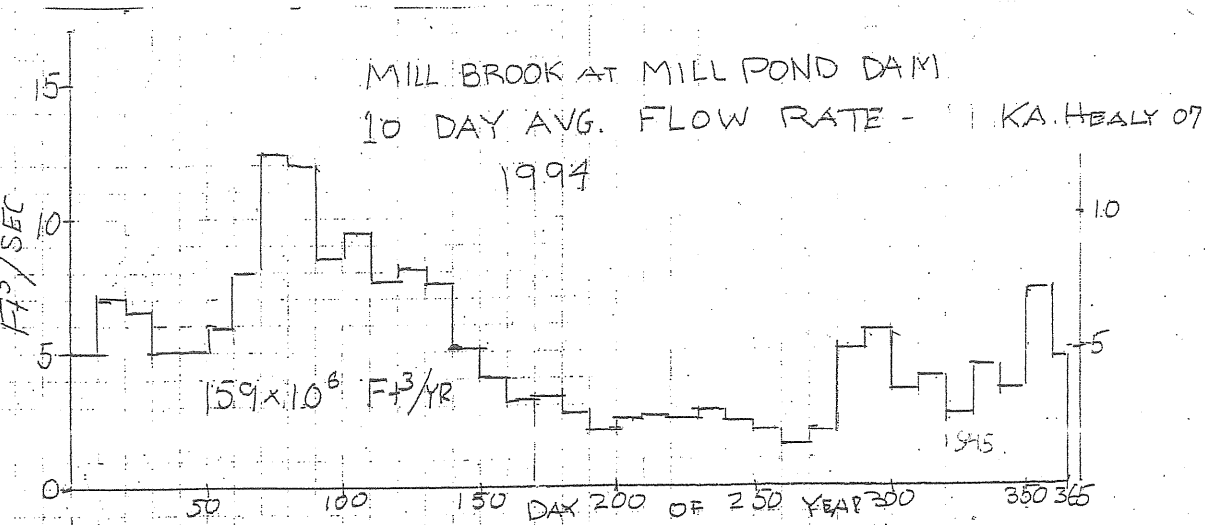
| | | | | FLOW INTO POND MEASURED DIRECTLY | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 10 DAYS 2012 | POND ELEV | CHANNEL | AREA GND WATER | STREAM FLOW | RAIN ON POND | BARRIER BEACH FLOW | POND STORAGE | CALCULATED GND WATER INTO POND: POND STORAGE – $(Q_S + Q_R + Q_B)$ | CALCULATED GND WATER INTO OCEAN: GND WATER FLOW – GND WATER INTO POND |
| 70-80 | +5.0 | CLOSED | 12.9 | 11 | 0.5 | –12 | +7 | 7 – (11 + 0.5 – 12) = 6.5 | 12.9 – 6.5 = 6.4 |
| 126-136 | +2.0 | OPEN | 12.9 | 10 | 8 | +5 | 0 | ? | |
| 148-158 | +3.0 | CLOSED | 12.9 | 8 | 2 | +2.7 | +20 | 20 – (8 + 2 + 2.7) = 7.3 | 12.9 – 7.3 = 5.6 |

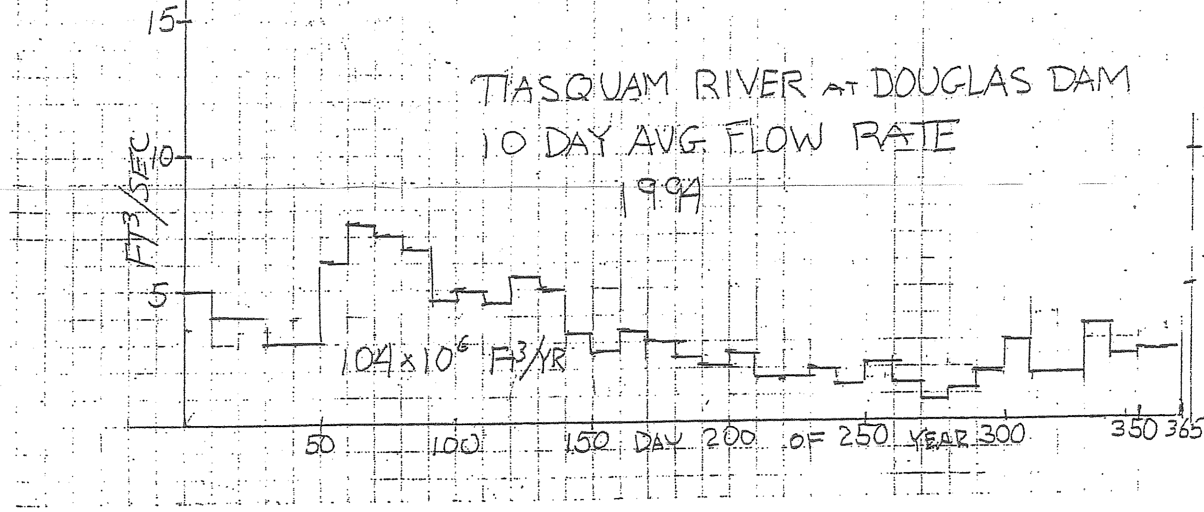

MILL BROOK AT MILL POND DAM
10 DAY AVG. FLOW RATE -
KA. HEALY 07
1994
$FT^3/SEC$
$159 \times 10^6$ $FT^3/YR$
DAY OF YEAR
0
5
10
15
50
100
150
200
250
300
350
365

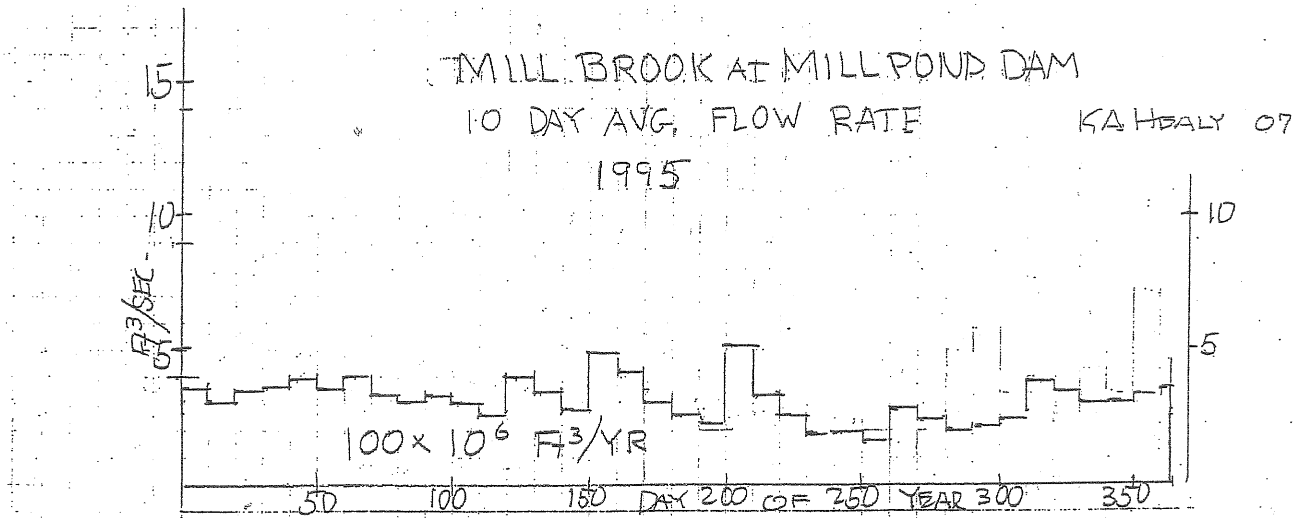

TIASQUAM RIVER AT DOUGLAS DAM
10 DAY AVG FLOW RATE
1994
$FT^3/SEC$
$104 \times 10^6$ $FT^3/YR$
DAY OF YEAR
5
10
15
50
100
150
200
250
300
350
365

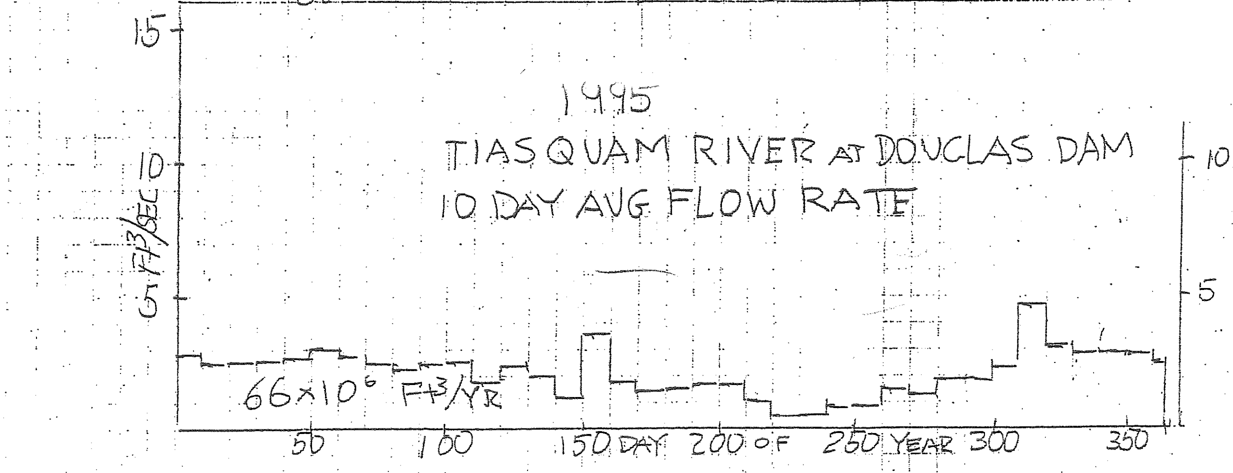

MILL BROOK AT MILL POND DAM
10 DAY AVG. FLOW RATE
KA HEALY 07
1995
$FT^3/SEC$
$100 \times 10^6$ $FT^3/YR$
DAY OF YEAR
5
10
15
50
100
150
200
250
300
350

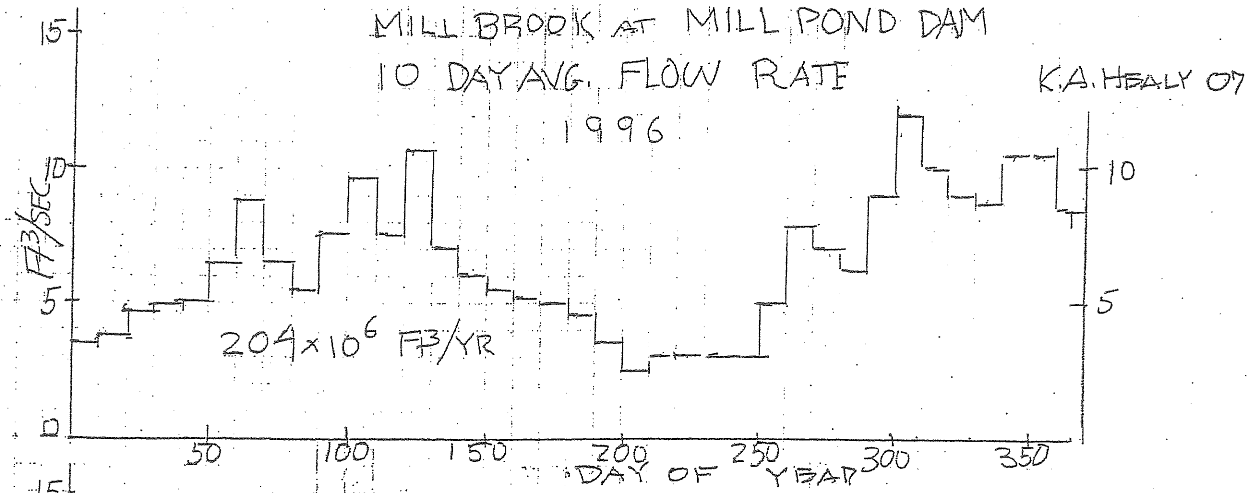

1995
TIASQUAM RIVER AT DOUGLAS DAM
10 DAY AVG FLOW RATE
$FT^3/SEC$
$66 \times 10^6$ $FT^3/YR$
DAY OF YEAR
5
10
15
50
100
150
200
250
300
350

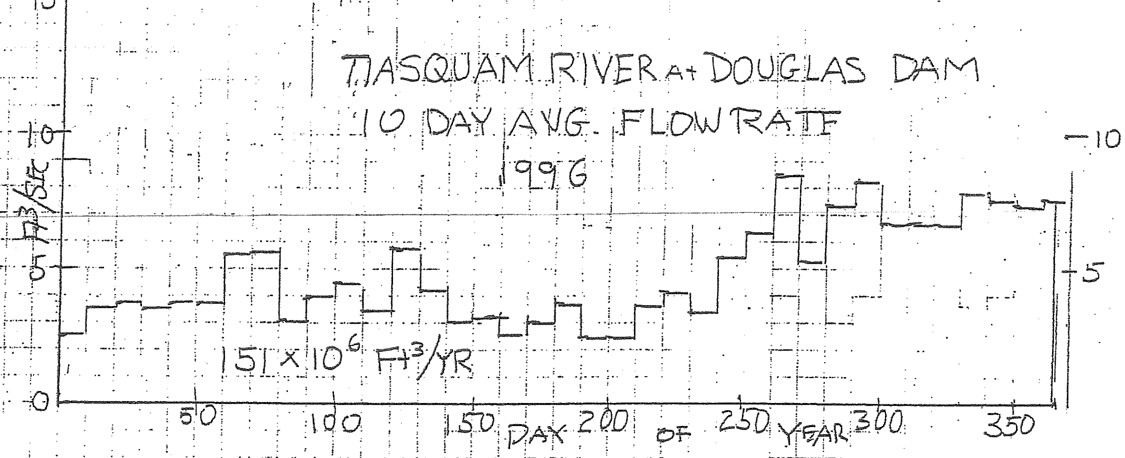

MILL BROOK AT MILL POND DAM
10 DAY AVG. FLOW RATE -
KA. HEALY 07
1994
$Ft^3$/SEC
159×10⁶ $Ft^3$/YR
DAY 200 OF 250 YEAR 300
0
5
10
15
50
100
150
350 365
1.0
5

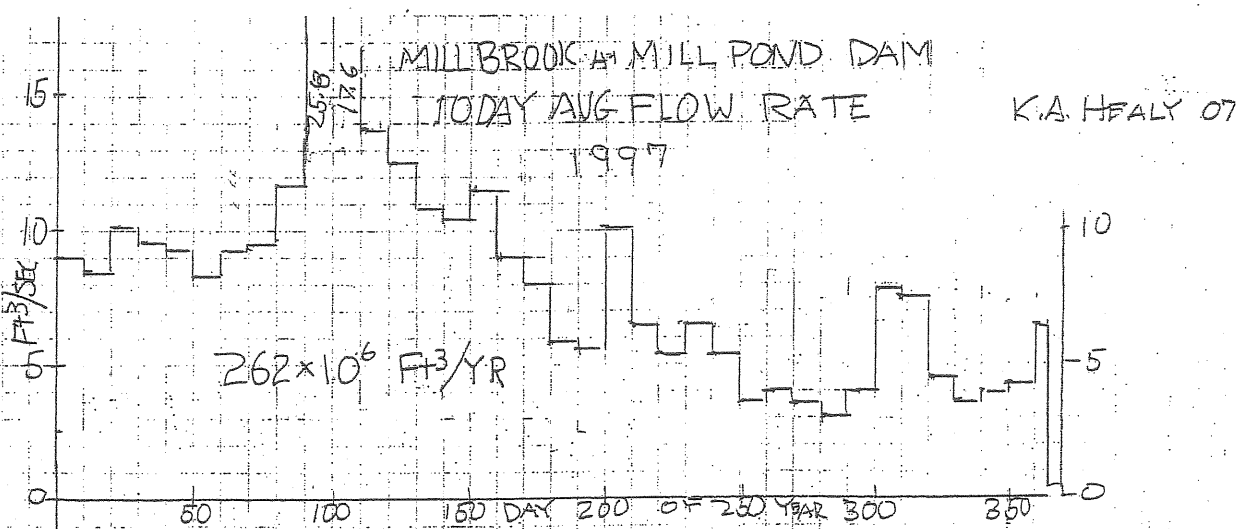

TIASQUAM RIVER AT DOUGLAS DAM
10 DAY AVG FLOW RATE
1994
$Ft^3$/SEC
104×10⁶ $Ft^3$/YR
DAY 200 OF 250 YEAR 300
5
10
15
50
100
150
350 365

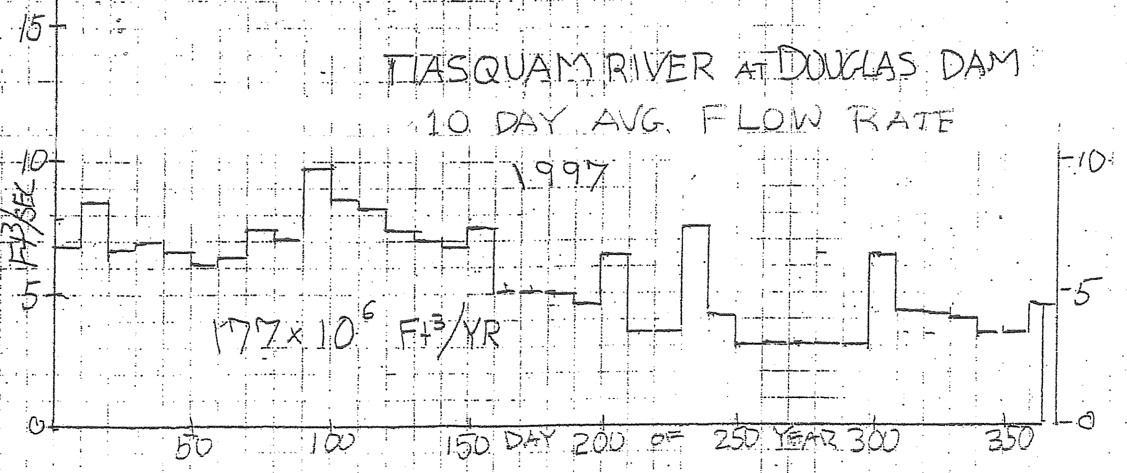

MILL BROOK AT MILL POND DAM
10 DAY AVG. FLOW RATE
KA HEALY 07
1995
$Ft^3$/SEC
100×10⁶ $Ft^3$/YR
DAY 200 OF 250 YEAR 300
5
10
15
50
100
150
350

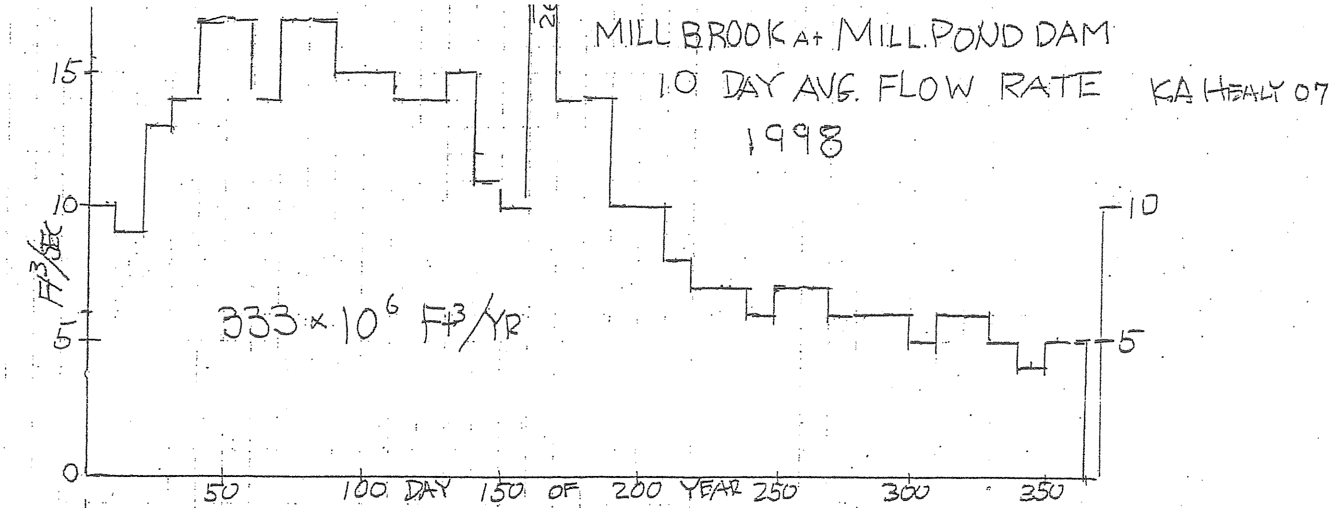

1995
TIASQUAM RIVER AT DOUGLAS DAM
10 DAY AVG FLOW RATE
$Ft^3$/SEC
66×10⁶ $Ft^3$/YR
DAY 200 OF 250 YEAR 300
5
10
15
50
100
150
350

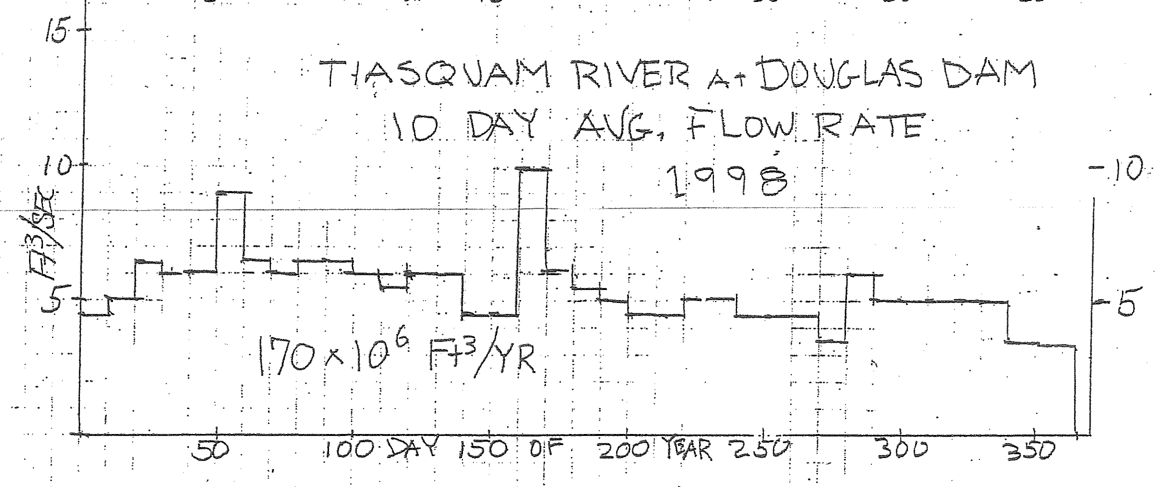

MILL BROOK AT MILL POND DAM
10 DAY AVG. FLOW RATE
1996
K.A. HEALY 07
FT3/SEC
204×10^6 FT3/YR
DAY OF YEAR
0
5
10
15
50
100
150
200
250
300
350

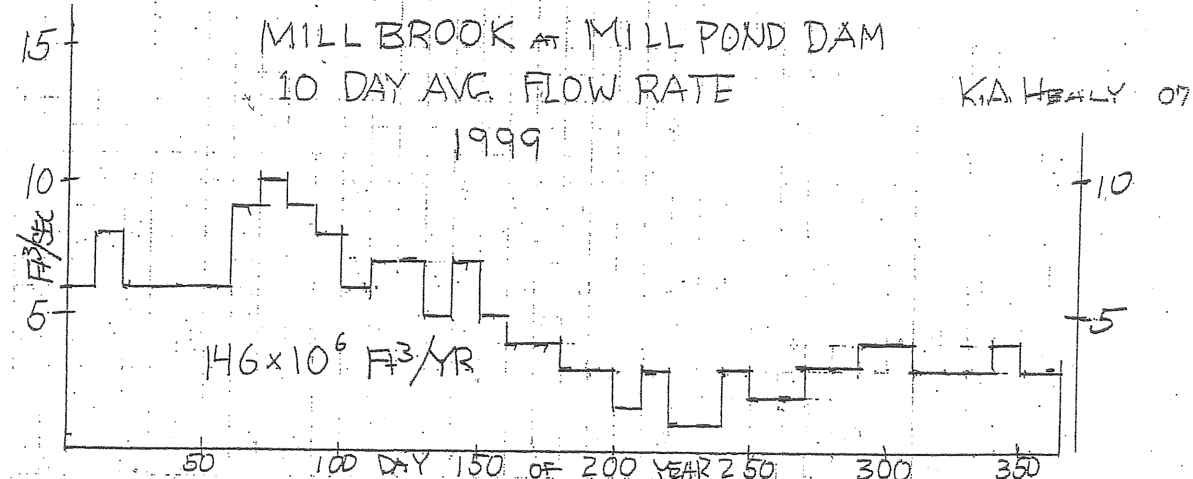

TIASQUAM RIVER At DOUGLAS DAM
10 DAY AVG. FLOW RATE
1996
FT3/SEC
151×10^6 FT3/YR
DAY OF YEAR
0
5
10
15
50
100
150
200
250
300
350

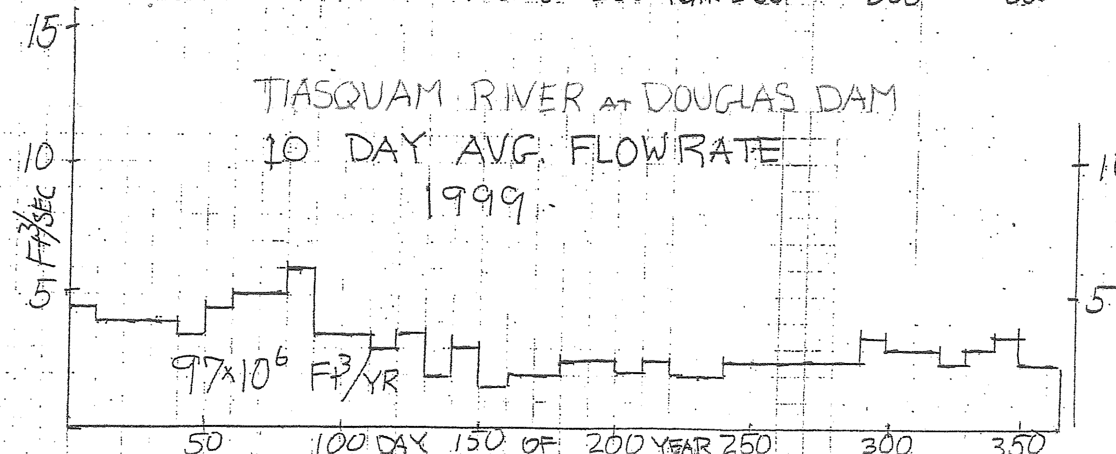

MILLBROOK At MILL POND DAM
10 DAY AVG FLOW RATE
1997
K.A. HEALY 07
25.6
17.6
FT3/SEC
262×10^6 FT3/YR
DAY OF YEAR
0
5
10
15
50
100
150
200
250
300
350

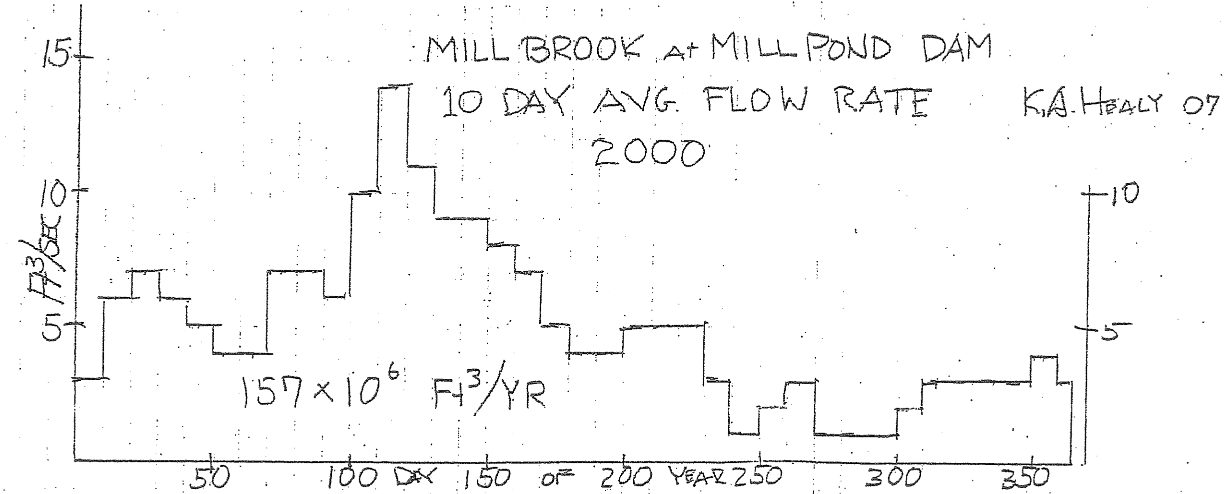

TIASQUAM RIVER AT DOUGLAS DAM
10 DAY AVG. FLOW RATE
1997
FT3/SEC
177×10^6 FT3/YR
DAY OF YEAR
0
5
10
15
50
100
150
200
250
300
350

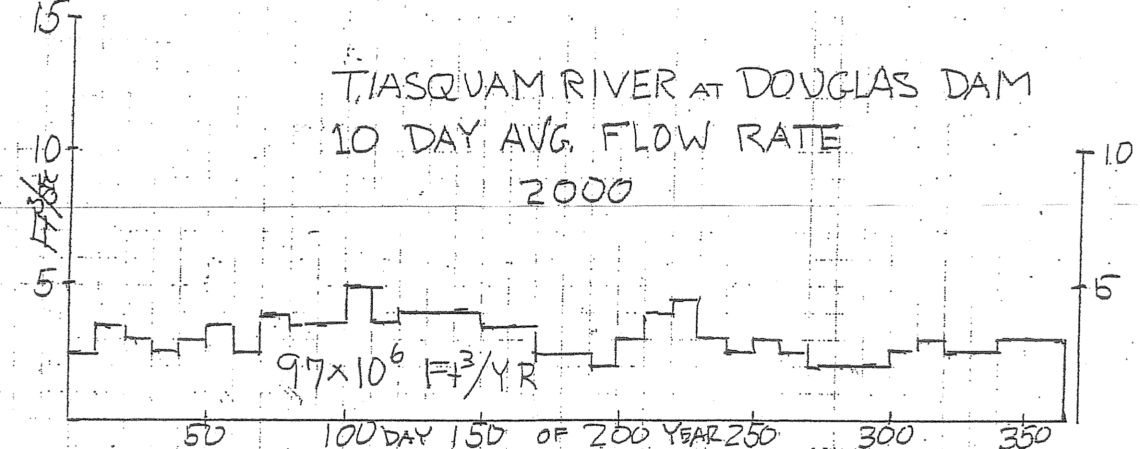

MILL BROOK At MILL POND DAM
10 DAY AVG. FLOW RATE
1998
KA HEALY 07
FT3/SEC
333 × 10^6 FT3/YR
0
5
10
15
50
100 DAY 150 OF 200 YEAR 250
300
350

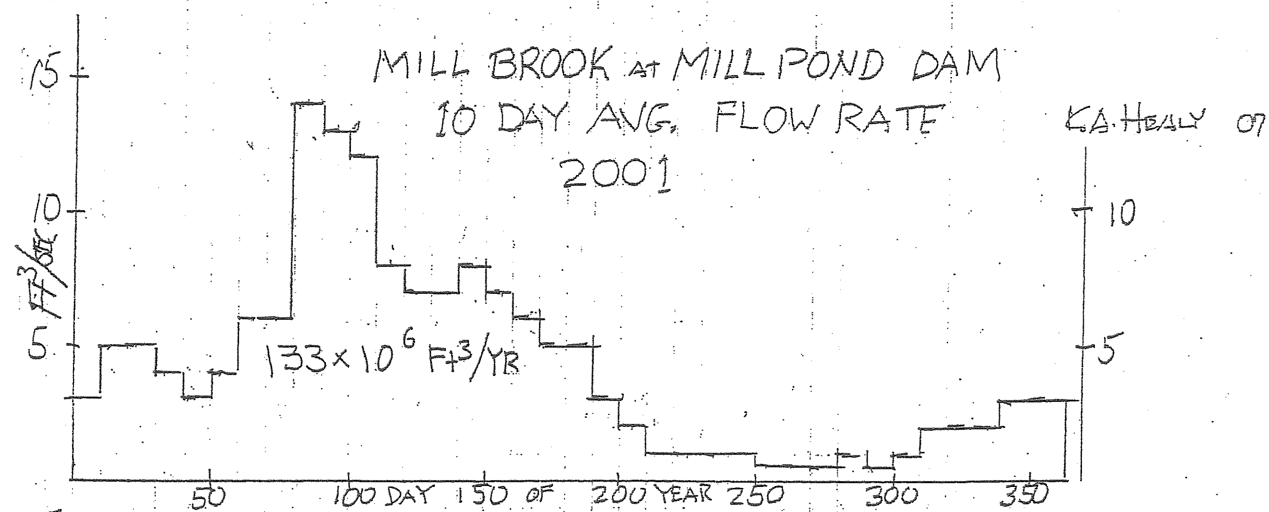

TIASQUAM RIVER At DOUGLAS DAM
10 DAY AVG. FLOW RATE
1998
FT3/SEC
170 × 10^6 FT3/YR
5
10
15
50
100 DAY 150 OF 200 YEAR 250
300
350

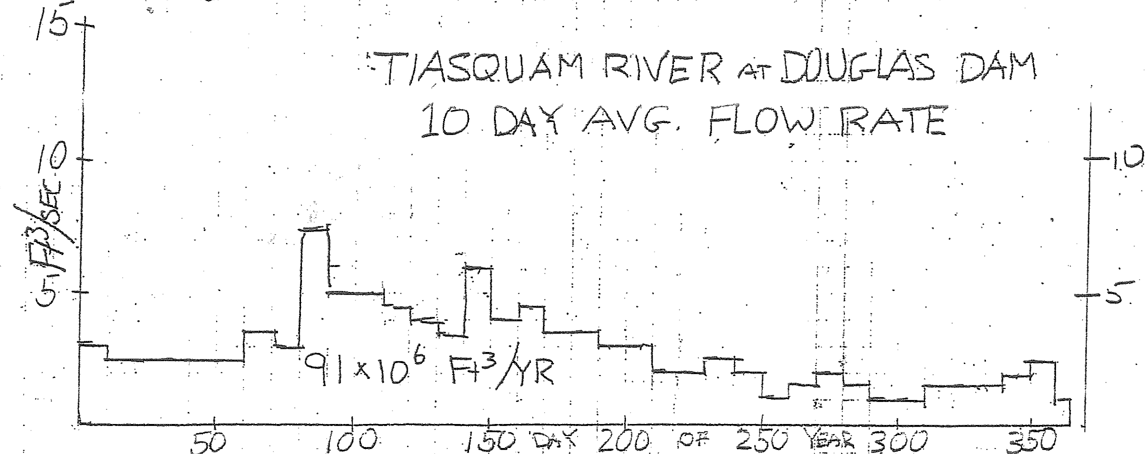

MILL BROOK At MILL POND DAM
10 DAY AVG. FLOW RATE
1999
K.A. HEALY 07
FT3/SEC
146 × 10^6 FT3/YR
5
10
15
50
100 DAY 150 OF 200 YEAR 250
300
350

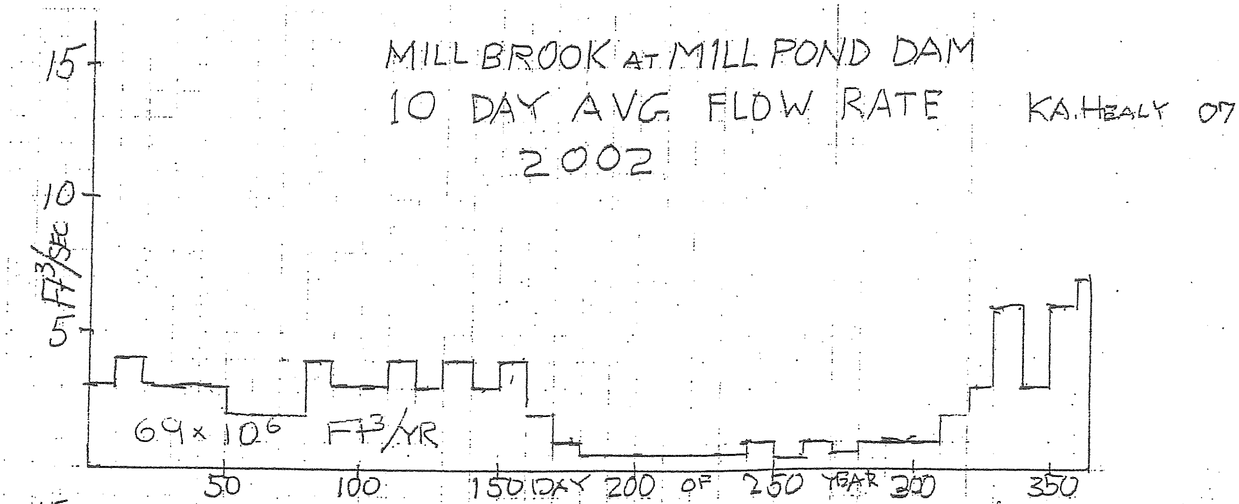

TIASQUAM RIVER At DOUGLAS DAM
10 DAY AVG. FLOW RATE
1999
FT3/SEC
97 × 10^6 FT3/YR
5
10
15
50
100 DAY 150 OF 200 YEAR 250
300
350

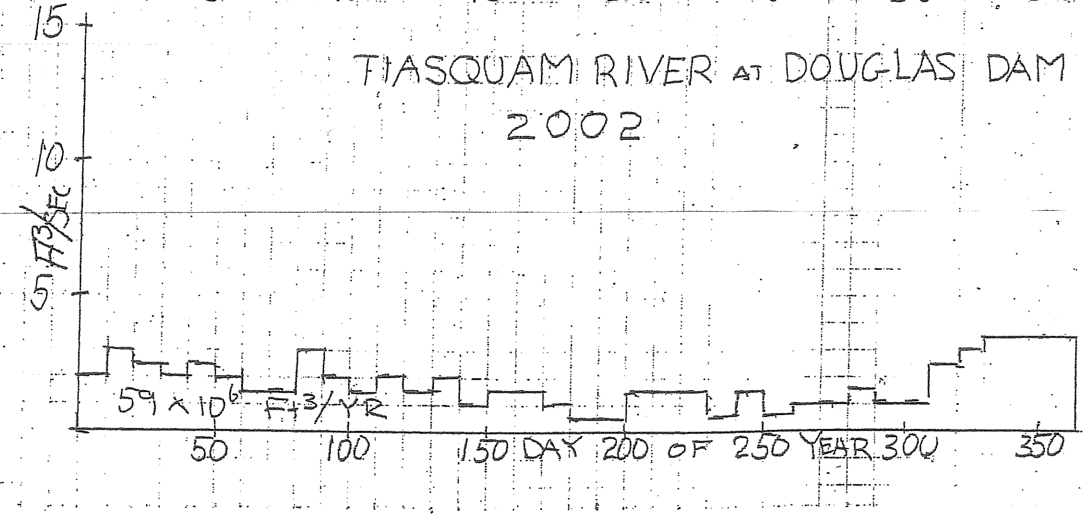

MILL BROOK AT MILL POND DAM
10 DAY AVG. FLOW RATE
2000
K.A. HEALY 07
15
10
5
FT3/SEC
157 × 10^6 FT3/YR
50
100 DAY 150 OF 200 YEAR 250
300
350

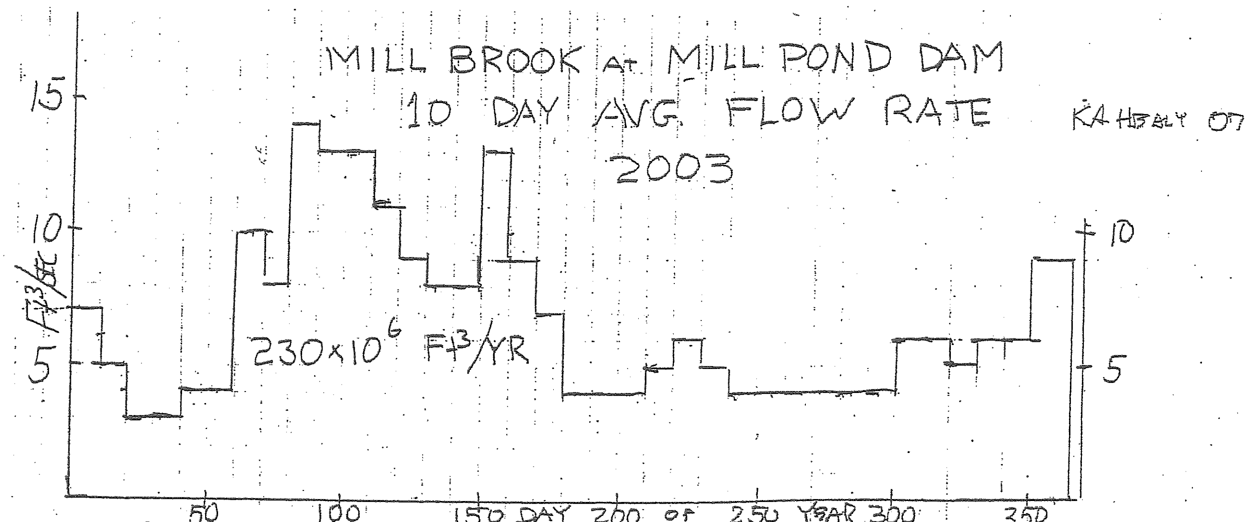

TIASQUAM RIVER AT DOUGLAS DAM
10 DAY AVG. FLOW RATE
2000
15
10
5
FT3/SEC
97 × 10^6 FT3/YR
50
100 DAY 150 OF 200 YEAR 250
300
350

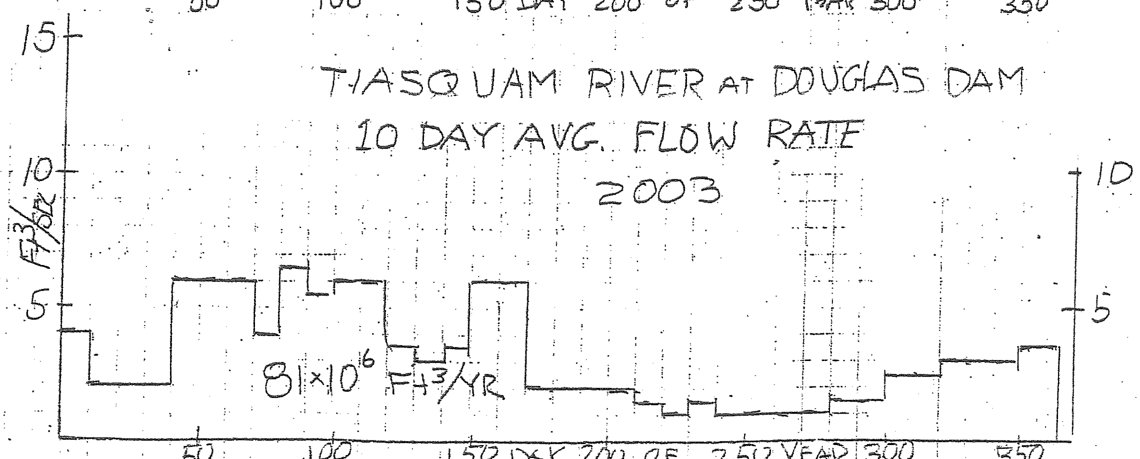

MILL BROOK AT MILL POND DAM
10 DAY AVG. FLOW RATE
2001
K.A. HEALY 07
15
10
5
FT3/SEC
133 × 10^6 FT3/YR
50
100 DAY 150 OF 200 YEAR 250
300
350

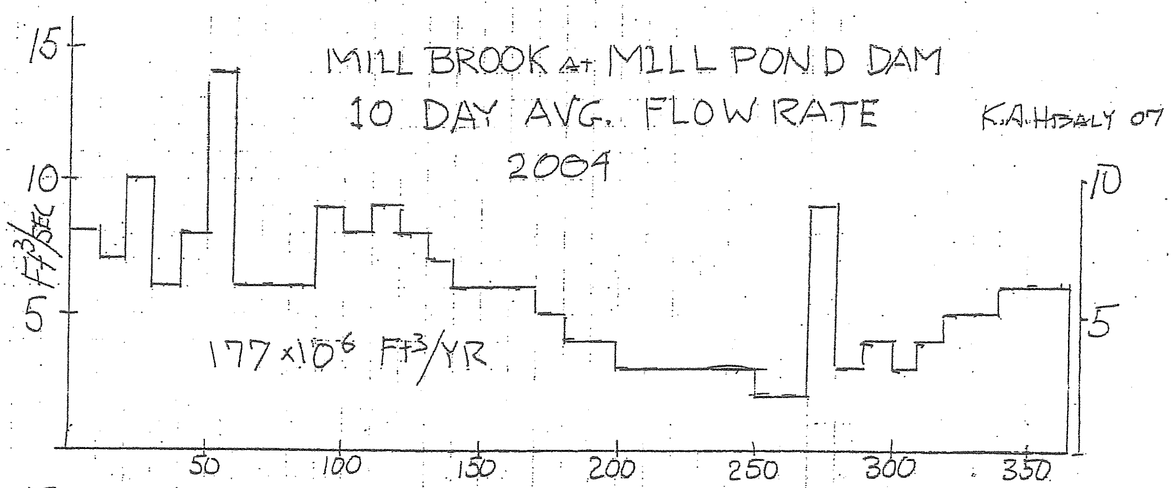

TIASQUAM RIVER AT DOUGLAS DAM
10 DAY AVG. FLOW RATE
15
10
5
FT3/SEC
91 × 10^6 FT3/YR
50
100
150 DAY 200 OF 250 YEAR 300
350

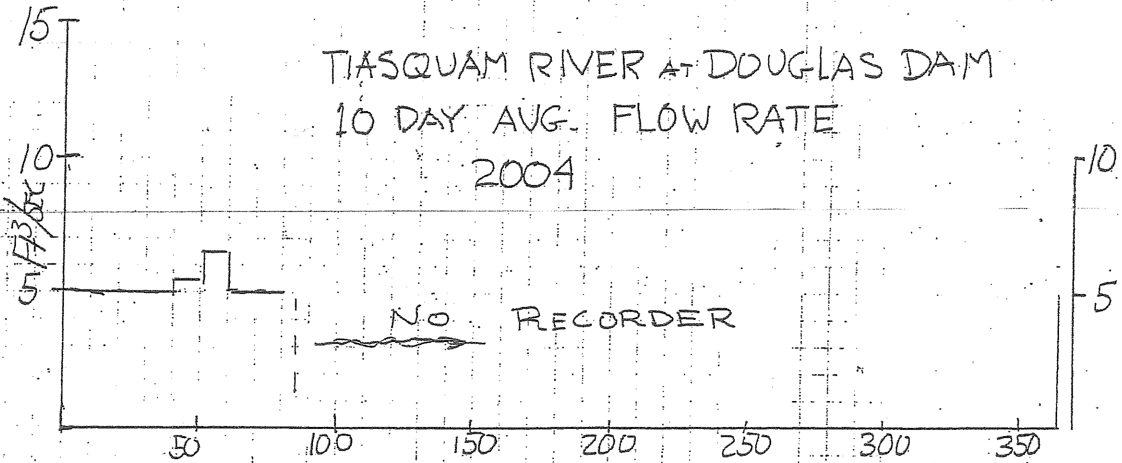

MILL BROOK AT MILL POND DAM
10 DAY AVG. FLOW RATE
2002
KA. HEALY 07
FT³/SEC
15
10
5
69 × 10⁶ FT³/YR
50
100
150 DAY 200 OF 250 YEAR 300
350

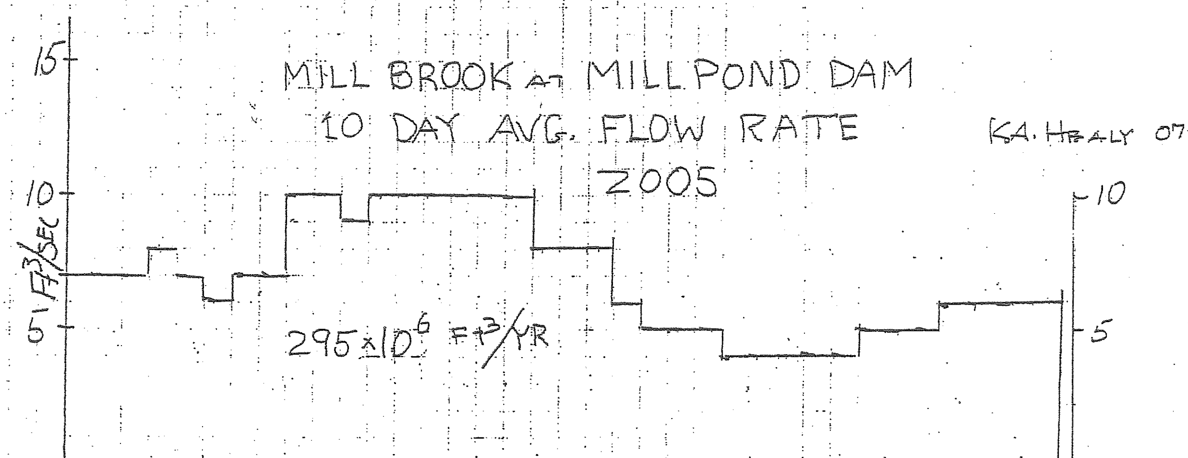

TIASQUAM RIVER AT DOUGLAS DAM
2002
FT³/SEC
15
10
5
59 × 10⁶ FT³/YR
50
100
150 DAY 200 OF 250 YEAR 300
350

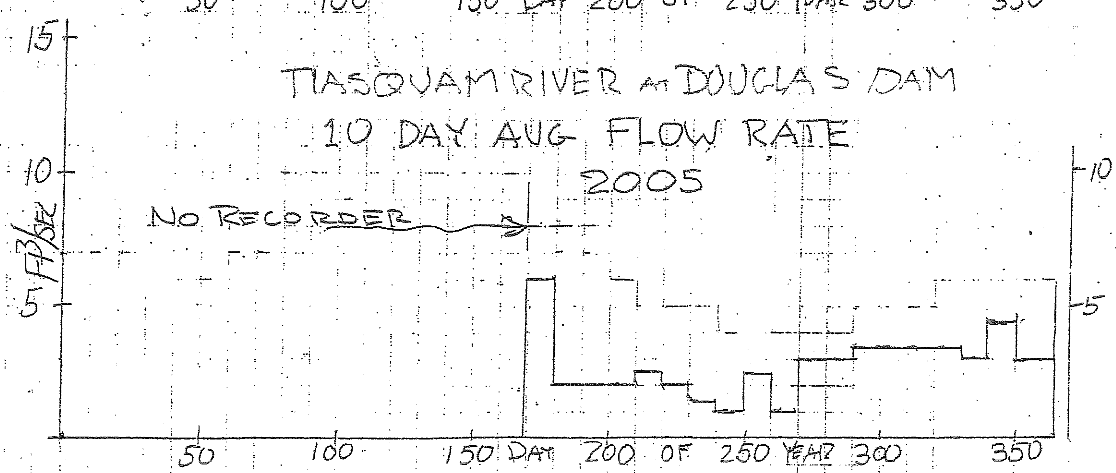

MILL BROOK AT MILL POND DAM
10 DAY AVG. FLOW RATE
2003
KA HEALY 07
FT³/SEC
15
10
5
230×10⁶ FT³/YR
50
100
150 DAY 200 OF 250 YEAR 300
350

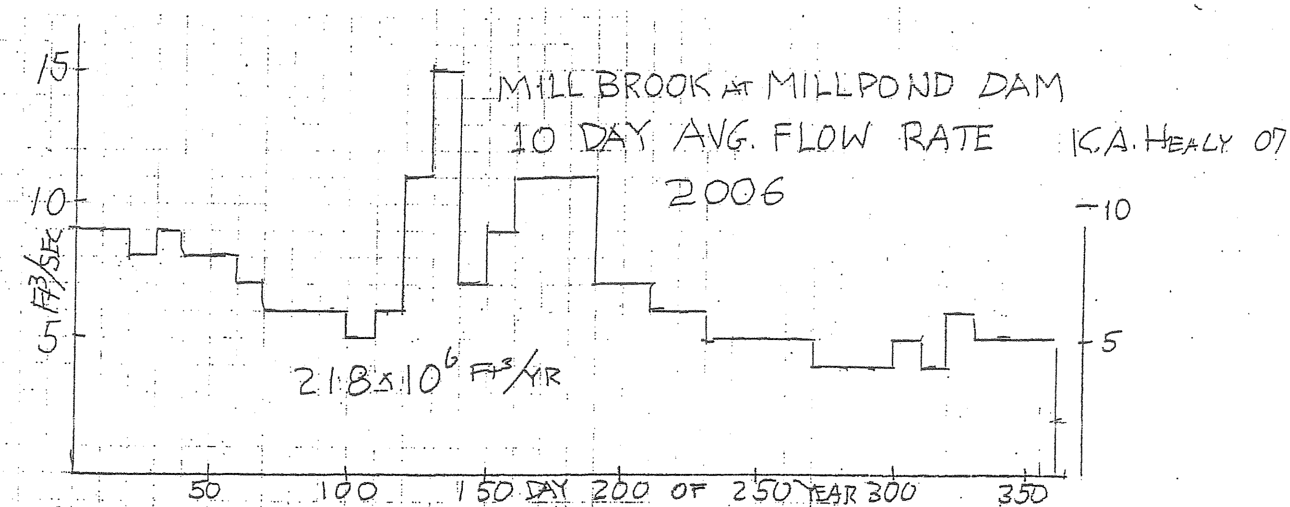

TIASQUAM RIVER AT DOUGLAS DAM
10 DAY AVG. FLOW RATE
2003
FT³/SEC
15
10
5
81×10⁶ FT³/YR
50
100
150 DAY 200 OF 250 YEAR 300
350

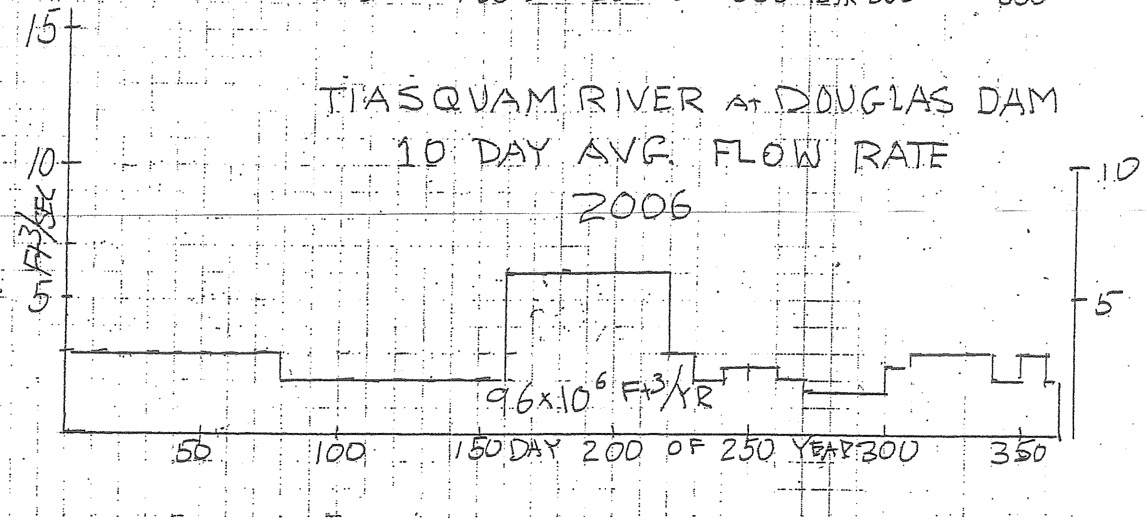

MILL BROOK AT MILL POND DAM
10 DAY AVG. FLOW RATE
2004
K.A. HEALY 07
$Ft^3/SEC$
$177 \times 10^6$ $Ft^3/YR$
15
10
5
50
100
150
200
250
300
350

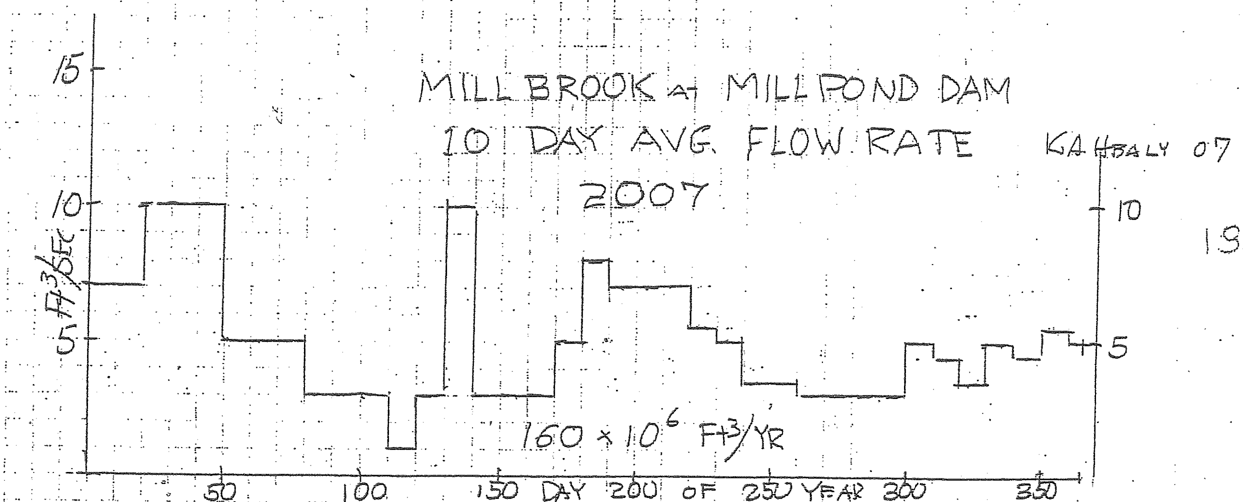

TIASQUAM RIVER AT DOUGLAS DAM
10 DAY AVG. FLOW RATE
2004
$Ft^3/SEC$
NO RECORDER
15
10
5
50
100
150
200
250
300
350


MILL BROOK AT MILLPOND DAM
10 DAY AVG. FLOW RATE
2005
K.A. HEALY 07
$Ft^3/SEC$
$295 \times 10^6$ $Ft^3/YR$
15
10
5
50
100
150 DAY 200 OF 250 YEAR 300
350

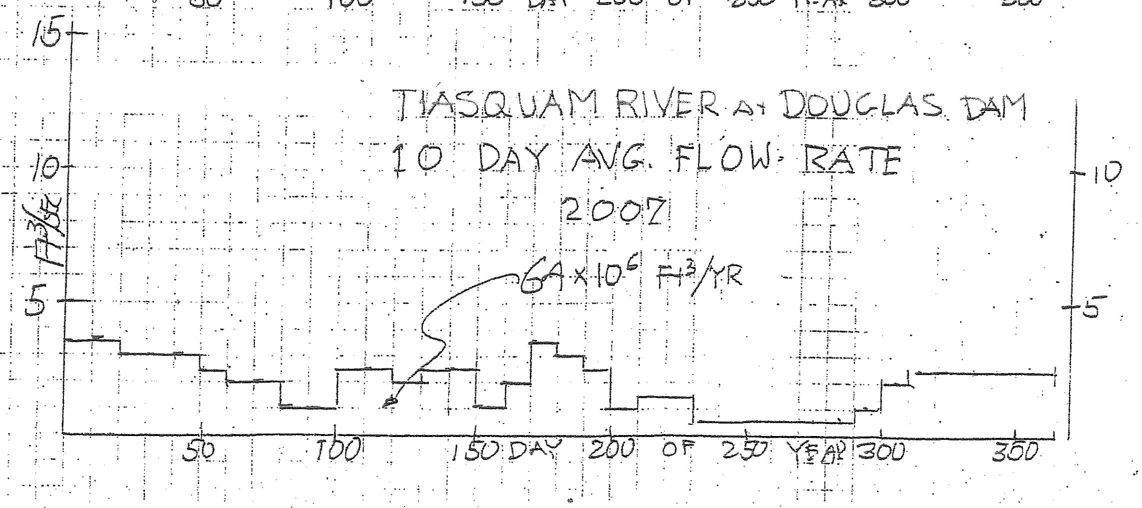

TIASQUAM RIVER AT DOUGLAS DAM
10 DAY AVG FLOW RATE
2005
NO RECORDER
$Ft^3/SEC$
15
10
5
50
100
150 DAY 200 OF 250 YEAR 300
350

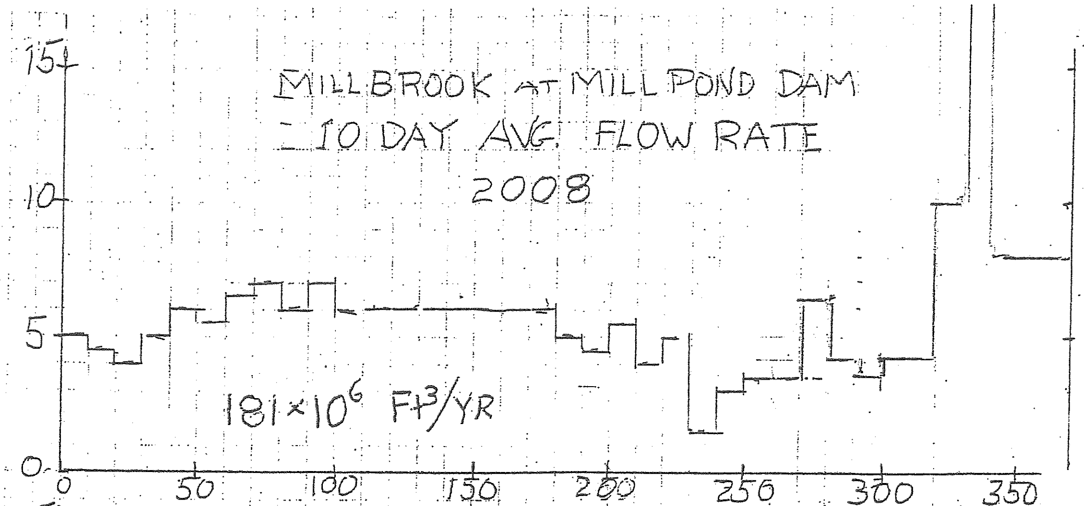

MILL BROOK AT MILLPOND DAM
10 DAY AVG. FLOW RATE
2006
K.A. HEALY 07
FT3/SEC
218×10^6 FT3/YR
DAY OF YEAR
15
10
5
50
100
150
200
250
300
350

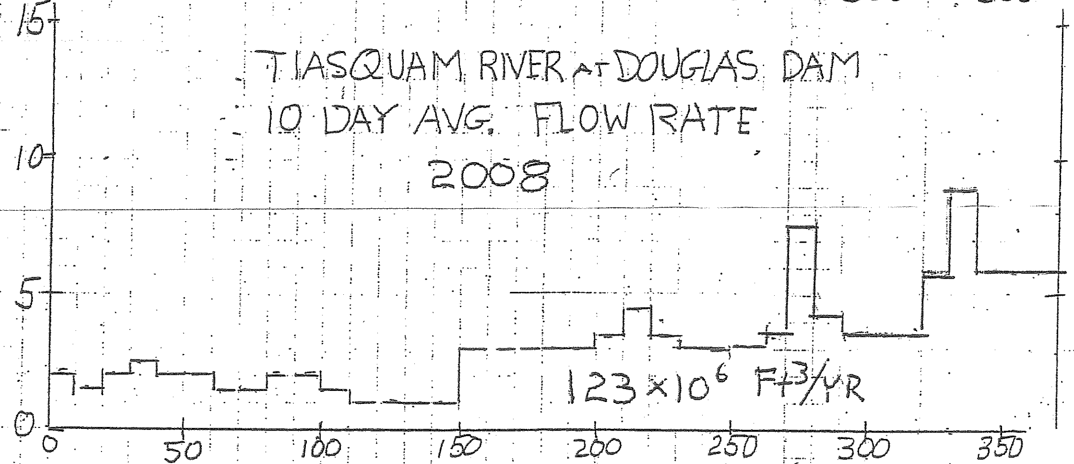

TIASQUAM RIVER AT DOUGLAS DAM
10 DAY AVG. FLOW RATE
2006
FT3/SEC
96×10^6 FT3/YR
DAY OF YEAR
15
10
5
50
100
150
200
250
300
350


MILL BROOK AT MILLPOND DAM
10 DAY AVG. FLOW RATE
2007
KA HEALY 07
FT3/SEC
160×10^6 FT3/YR
DAY OF YEAR
15
10
5
50
100
150
200
250
300
350

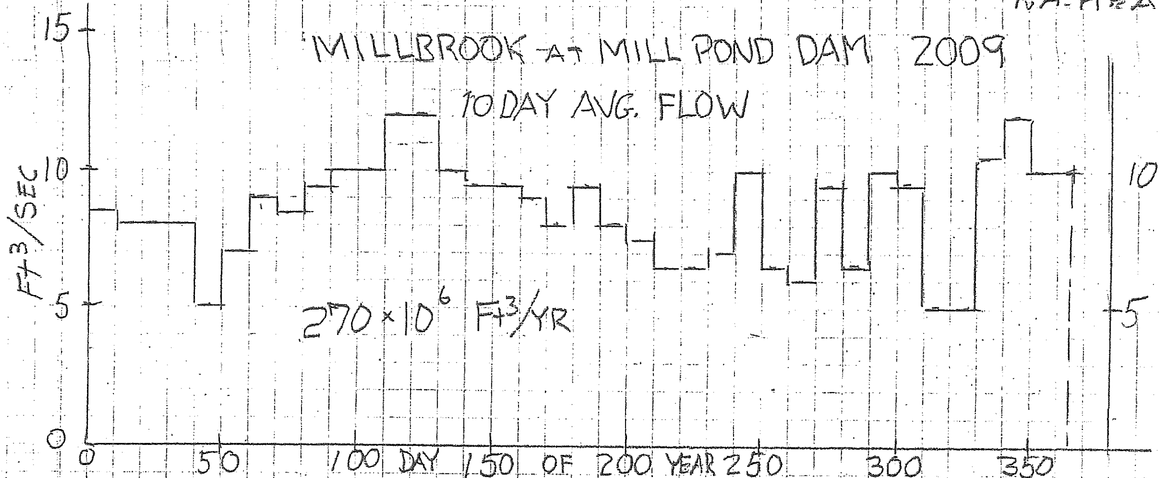
195

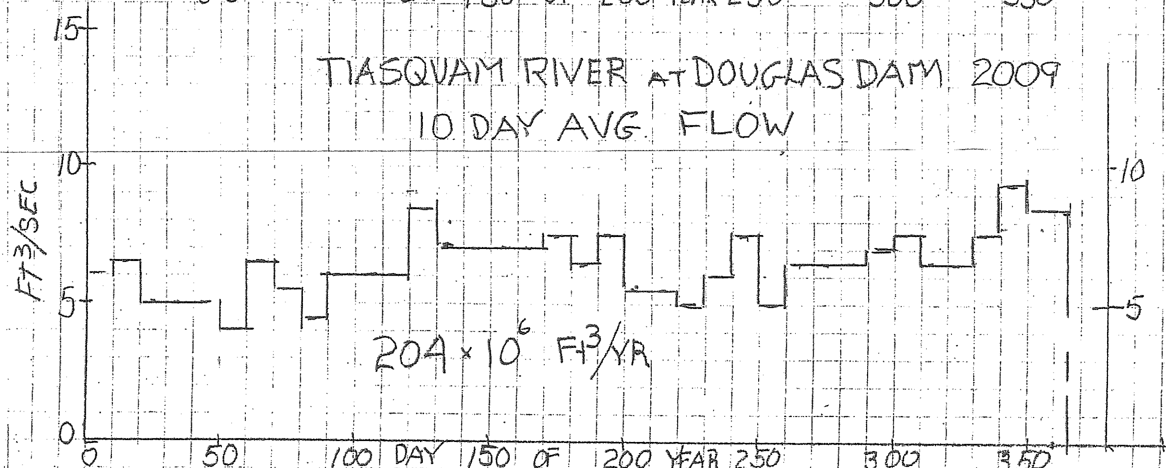

TIASQUAM RIVER AT DOUGLAS DAM
10 DAY AVG. FLOW RATE
2007
FT3/SEC
64×10^6 FT3/YR
DAY OF YEAR
15
10
5
50
100
150
200
250
300
350


MILLBROOK AT MILLPOND DAM
10 DAY AVG. FLOW RATE
2008
181×10^6 FT^3/YR
0
5
10
15
0
50
100
150
200
250
300
350

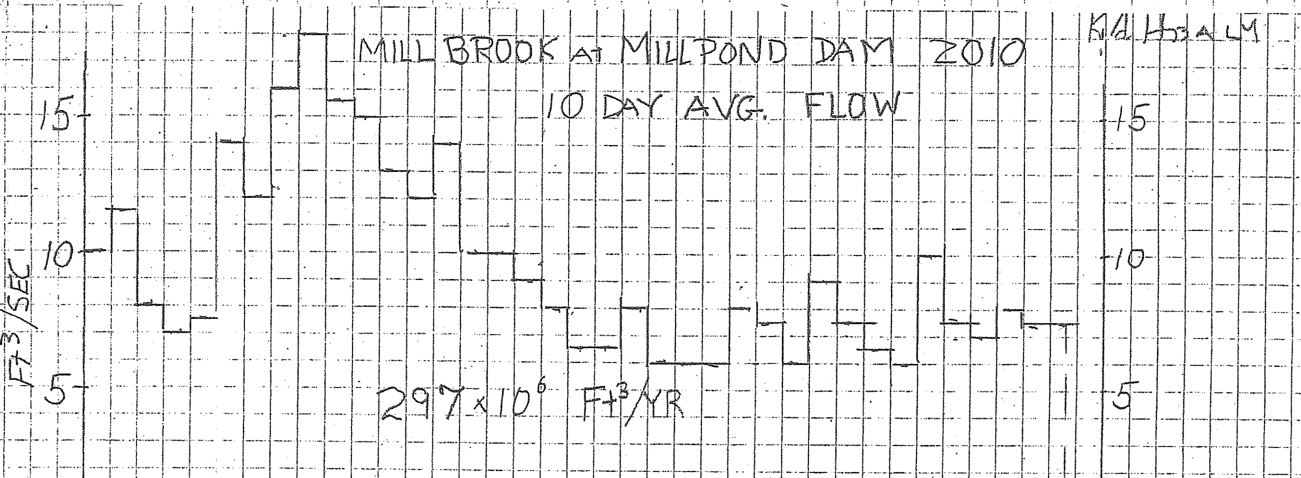

TIASQUAM RIVER AT DOUGLAS DAM
10 DAY AVG. FLOW RATE
2008
123×10^6 FT^3/YR
0
5
10
15
0
50
100
150
200
250
300
350

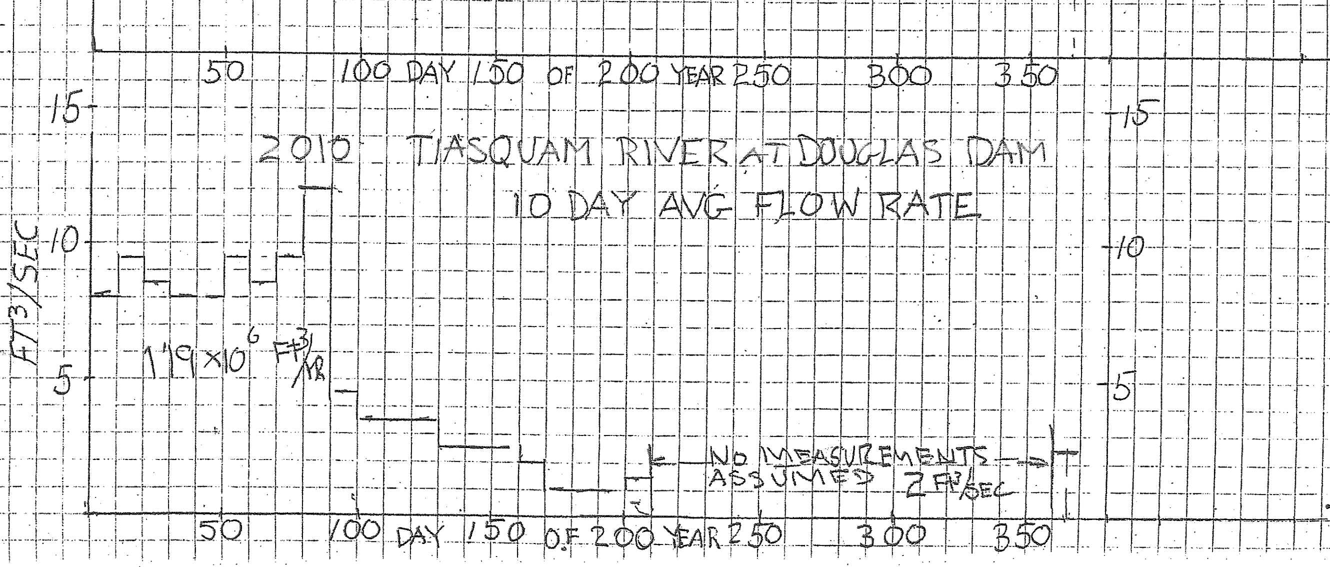
K.A. HEALY

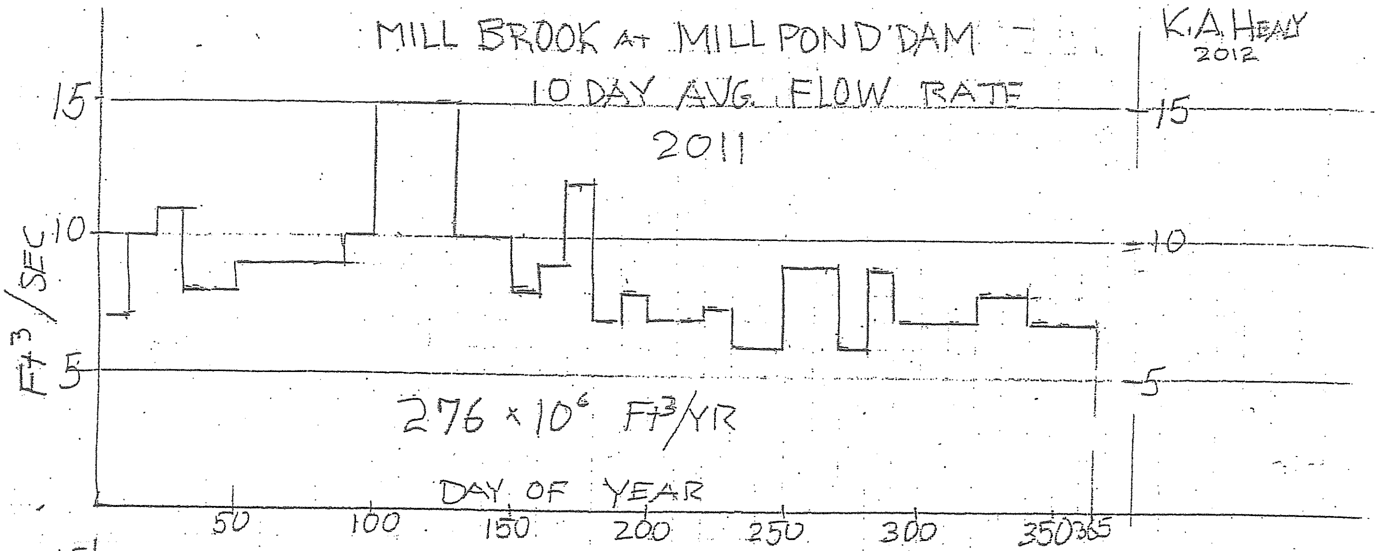


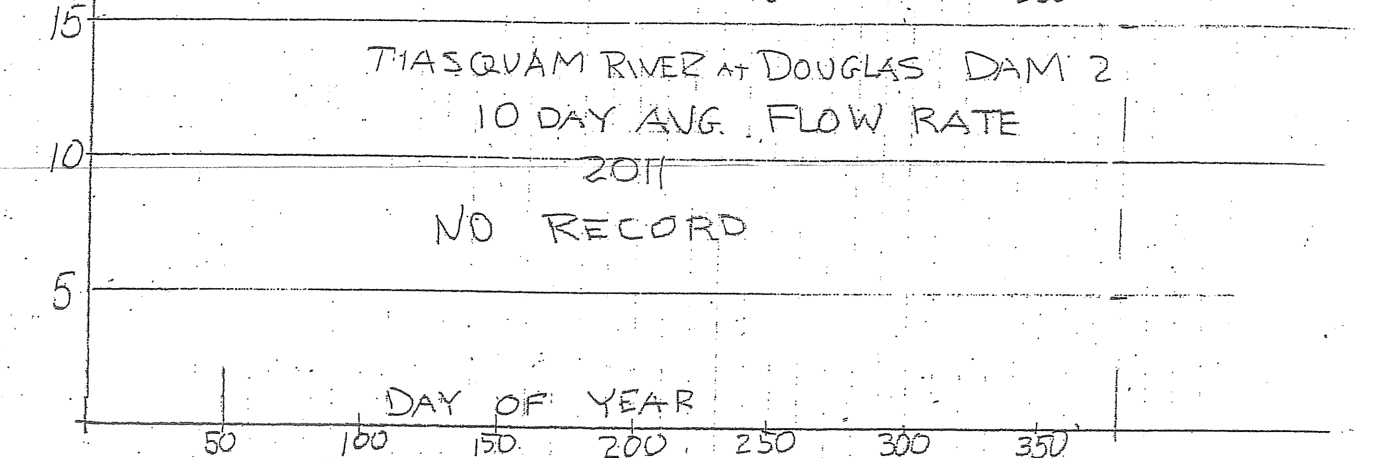



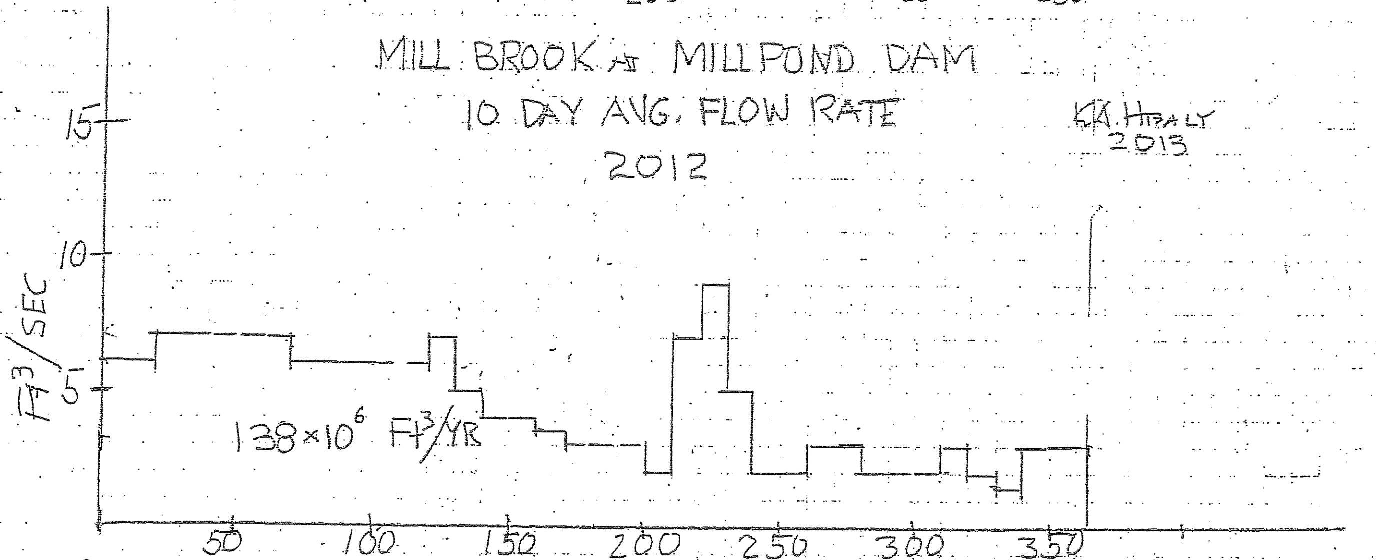

K.A. HEALY

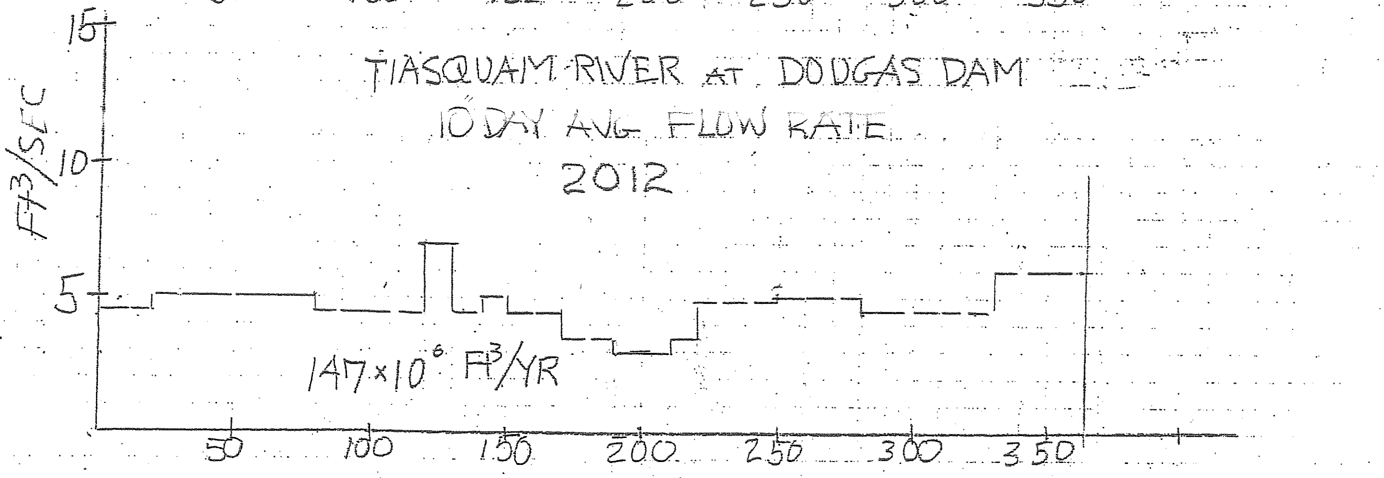



MILL BROOK AT MILL POND DAM
10 DAY AVG. FLOW RATE
2011
K.A. HEALY 2012
276 × 10^6 FT^3/YR
FT^3/SEC
DAY OF YEAR
15
10
5
50
100
150
200
250
300
350
365


TIASQUAM RIVER AT DOUGLAS DAM 2
10 DAY AVG. FLOW RATE
2011
NO RECORD
DAY OF YEAR
15
10
5
50
100
150
200
250
300
350


MILL BROOK AT MILLPOND DAM
10 DAY AVG. FLOW RATE
2012
K.A. HEALY 2013
138×10^6 FT^3/YR
FT^3/SEC
15
10
5
50
100
150
200
250
300
350


TIASQUAM RIVER AT DOUGAS DAM
10 DAY AVG. FLOW RATE
2012
147×10^6 FT^3/YR
FT^3/SEC
15
10
5
50
100
150
200
250
300
350