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From: Lamonte, Thomas (DEP)
Sent: Thursday, September 11, 2003 12:04 PM
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Subject: safe yield

Attachments: Safe yield-Final.doc

Attached is a technical memo on Safe Yield. While the document characterization is noted as Draft Final Memo For Internal Use, it should be regarded as final.

As you may recall, safe yield as described in the wm regulation, 310 CMR 36.31, has been a problem for the Water Management Program for some time and this difficulty led the wm program to discontinue safe yield determinations.

Recent USGS work with low streamflow in the Ipswich Basin, along with legal concerns for wm permits, has re-focused attention on safe yield. However, due to its long-term abandonment, current staff are quite unfamiliar with conceptual and technical aspects. In re-visiting safe yield, the first task of order is to make the method transparent. The attached memo reviews the safe yield methodology and illustrates an application with the Ipswich River Basin where safe yield was determined to be 3.5 mgd, with a floodskimming safe yield of 8.0 mgd.

Once we better understand safe yield in its current form, we will be better prepared to make necessary changes and adjustments (a long term effort), if we intend to have a comprehensive tool for allocating water resources in a basin.

Water Management staff earmarked to attend the wm subcommittee meeting scheduled for October 6th, should be prepared to discuss and brainstorm the issue at the meeting.

Thanks to the technical group who worked on this issue.

Tom

Safe yield-Final.doc
(158 KB)

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---- FINAL DRAFT MEMORANDUM FOR INTERNAL USE ----

TO: Duane LeVangie, Manager, Water Management Program
FROM: Tom Lamonte, EA Water Management Program
RE: Safe Yield
CC: Paul Blain, DWP; Steve Hallem, DWP, Kellie O'Keefe, NERO
Barbara Kickham, CERO; Vicki Gartland, DCR
DATE: September 11, 2003

Safe Yield, as described in Water Management Regulations, 310 CMR 36.31, was intended to provide a regulatory tool for comprehensive management of the Commonwealth's water resources. The Department's safe yield was developed in concert with and dependent on WRC/DEM's Basin Plans with minimum streamflow. However, early in the 1990's, WRC/DEM discontinued their Basin Plans due to considerable flaws with that approach. Meanwhile, DEP's safe yield methodology, based on Neil Fennessey's work, circa 1990, ran into its own problems. Assumptions in the methodology were questioned and in the limited applications where the safe yield method was employed, results were problematic. Furthermore, when WRC/DEM Basin Plans were discontinued, it was only a matter of time before DEP's safe yield methodology had to be abandoned, and the Water Management Program set aside further determinations of safe yield. At present, particularly in light of recent USGS studies on streamflow, the safe yield method can be considered conceptually inadequate and technically deficient. Still, the failure to resolve the safe yield issue has led to a legal crisis with withdrawal permits and adverse impacts to the environment.

The purpose of this memo is to review and critique safe yield, or basin yield, as described in the regulations, and to illustrate the methodology through an application with the Ipswich River Basin - where safe yield was determined to be 3.5 mgd, and a safe yield for flood skimming was determined to be 8.0 mgd. This review would not have been possible had it not been for Fennessey's remaining files and his hand written notes from that period. The validation for this analysis is seen in the successful reproduction of Fennessey's USGS stream data set, calculations and flow duration curves with one notable exception. Despite the criticism noted herein, Fennessey is credited with methodology strong points of creating the safe yield technical concept, introducing a stream flow duration measure, and developing a safe yield methodology at a time when only limited scientific knowledge on safe yield was available.

Related regulatory definitions, 310 CMR 36.03: *(Regulations in italics)*

<u>Safe Yield</u> *means the maximum annually averaged daily water use consumptive loss rate that can be sustained from a water source with an acceptable degree of risk.*

Water Source means any natural or artificial aquifer or body of surface water including its watershed where ground and surface water sources are interconnected in a single hydrologic system. For the purpose of these regulations a river basin defined by the Commission is considered to be a water source except that for purposes of safe yield calculations and application review only a water source may be determined by the Department to be either a river basin or a hydrologically distinct portion thereof, dependent on information satisfactory to the Department for the establishment of safe yield. For the purpose of public comment periods established in 310 CMR 36.22 and 36.23 only, a water source shall be defined by the Department as a hydrologically distinct subbasin.

Consumptive Loss means that portion of a withdrawal which is estimated by the Department not to be discharged back from which it was withdrawn. The Department's estimation of the portion of a withdrawal considered to be consumptively lost to the basin shall be based upon the use to which the withdrawal is put and any interbasin transfer.

Floodskimming means withdrawing volumes of water from surface or groundwater during a period limited to the floodskimming season, as determined by the Department.

310 CMR 36.31 Safe Yield (applied to the Ipswich River Basin) *(regulations in italics)*

310 CMR 36.31(1)
The Department may, in any determination of safe yield by water source, consider at least the following:

(a) minimum streamflow
(b) water balance
(c) hydrological impacts of proposed, existing and permitted withdrawal
(d) the safe yield of any severely impacted subbasin within the water source
(e) any additional application information

310 CMR 36.31(2)
In water sources deemed appropriate by the Department, safe yield shall be determined using surface water streamflow analysis.

(a) Where adequate streamflow data exist, the Department will estimate the average daily streamflow during the months of July, August and September for the years 1980 and 1981 recorded at a gage location in the basin selected by the Department.

(b) Where streamflow gage records are inadequate .... (not the case with Ipswich)

USGS stream data for the Ipswich River from the Ipswich Gage #01102000 with a contributing drainage area of 125 square miles, was the basis for this analysis and was used to replicate Fennessey's work. The average daily streamflow for the total designated 6 month period was determined to be 31.33 cfs (Fennessey).

Fennessey expressed Safe Yield with the following equation:

$$\text{Safe Yield} = \left[E[\,Q_{80/81}\,] - DA_g Q_{min} \right] \frac{DA_b}{DA_g}$$

In the equation, E [$Q_{80/81}$] equals the average summer time streamflow estimated during the DEM planning drought of 1980 and 1981; DA_g equals the drainage area of the USGS streamgage used to estimate that statistic; Q_{min} equals the WRC minimum streamflow value, and DA_b equals the drainage area of the river basin being considered that lies within the Massachusetts borders. (Fennessey)

(c) The Commission's water management reference streamflow value scaled to the gage watershed area shall then be subtracted from the average daily streamflow determined in (a) or (b)

31.33 cfs	average daily streamflow (summer 1980-1981)
- 27.00 cfs	WRC's 0.216 cfsm minimum streamflow at Ipswich Gage
4.33 cfs	

(d) The Department shall rescale the resultant value to the entire drainage area of the water source within the borders of the Commonwealth to determine the safe yield for that water source.

$$\frac{4.33 \text{ cfs}}{125 \text{ sq. mi.}} : \frac{x}{155.94 \text{ sq. mi.}}$$

x = 5.4 cfs = 3.5 mgd BASIN YIELD / Ipswich Basin

<u>310 CMR 36.31(3)</u>

The Department shall use the safe yield determined according to 310 CMR 36.31(2) to construct a flow duration curve estimating average daily streamflow which is expected to occur in the future if the safe yield were removed from the basin. The Department shall compare this flow duration curve and a flow duration curve depicting the present state to estimate the increase in probability that streamflow will fall below the Commission's water management reference streamflow if all the safe yield is removed from the basin. The resultant increase in probability shall be used in assessing the impact of new withdrawals in 310 CMR 36.26(2)(a) and in determining the safe yield for flood skimming withdrawals.

A present state flow duration curve was constructed from USGS data for the period of record at that time (October 1, 1960 – September 30, 1989). A second curve, a future state flow duration (Worse Case Future State (Fennessey)), was constructed by subtracting the 4.33 cfs from the period of record. At the WRC minimum streamflow of 27 cfs, the probability shift from present state (77%) to future state

(74.2%) was determined to be 2.8%. Figure 1 illustrates Fennessey's present and future flow duration curves.

310 CMR 36.31(4)
In determining the safe yield for the flood skimming period, the Department shall use surface water streamflow analysis

(a) where adequate streamflow data exist, the Department will construct a period of record flow duration curve using average daily streamflow data during only the floodskimming period

(b) where streamflow gage records are inadequate... (not the case with Ipswich)

(c) The increase in probability that streamflow will fall below the Commission's water management reference streamflow as determined in 310 CMR 36.31(3) will be applied to the flow duration curve developed in 36.31(4)(a) or (b) and will be used to define the safe yield during the flood skimming period.

(d) The department shall establish a flood skimming period for each water source as it deems appropriate.

The flood skimming period determined by the Department was December 1 through May 31. This is the period when public water suppliers (Lynn, Peabody and Salem-Beverly), were permitted to have surface withdrawals directly from the river to fill their reservoirs.

A flood skimming present state flow duration curve was constructed from the period of record from December through May only. Applying the 2.8% probability shift obtained in Section 3, resulted in a difference of 10 cfs. The future state flow duration curve was generated by subtracting 10 cfs from the period of record. The 10 cfs differential obtained at the Ipswich Gage was rescaled to the entire watershed to determine the flood skimming safe yield for the basin. Figure 2 shows the present and future flow duration for flood skimming.

$$\frac{10 \text{ cfs}}{125 \text{ sq. mi.}} : \frac{x}{155.94 \text{ sq. mi.}}$$

x = 12.48 cfs = 8.0 mgd BASIN YIELD for flood skimming period

310 CMR 36.31(5)
The safe yield of a basin shall be deemed to be fully allocated when consumptive loses due to permitted withdrawals equal the amount determined in 310 CMR 36.31(2)(d) for non-floodskimming withdrawals. The floodskimming safe yield shall be deemed to be fully allocated when consumptive loses attributable to permitted withdrawals during the floodskimming period equal the amount determined in 310 CMR 36.31(4).

Consumptive losses were derived from USGS consumptive loss fraction data (Table 1) weighted according to the type of land use as reported by the permit applicant. Fennessey used a 1.2 summer peaking factor, along with an application of community loss rate and available yield for permitting. Calculation results are illustrated in Table 2. Tables 1 and 2 were reproduced from Fennessey's files. Individual community loss estimates were developed using the following expression:

$$Q_{LOSS} = \text{Peaking Factor} \times \text{Loss Fraction} \times Q_{PERMIT}$$

Table 1. USGS Consumptive Loses For Land Use (Estimated Water Use in U.S., 1985)

User Class	Loss Fraction (%)
Agriculture	100
Commercial	21.8
Industrial	22.2
Municipal	Not available (assume 17.1)
Residential	17.1
Unaccounted for	Not available (assume 0.0)

Table 2. Consumptive loses applied to Ipswich Basin communities: Permit Round I

Ipswich River Basin SafeYield: 3.5 mgd

	Annual Average Daily Withdrawal (mgd)	Loss Rate (mgd)
Danvers	1.00	1.00
Hamilton	0.35	0.07
North Reading	0.25	0.04
Salem-Beverly	1.13	1.25
Topsfield	0.20	0.03
Wilmington	0.80	0.89
Total:		3.28 mgd

Available Yield for permitting Round 2: 0.22 mgd

Flood Skimming Season Permit Applicants / 2008 DEM Projections Used
Ipswich River Basin Floodskimming Safe Yield: 8.0 mgd

	Loss Rate (mgd)
Lynn	1.40
Peabody	1.66
Salem-Beverly	1.52
Year-round withdrawals	3.28
Total:	7.86 mgd

Available Yield for permitting Round 2: 0.14 mgd

Method Reliability: USGS South Middleton Gage / Ipswich Basin

Transposing the basin yield results and flow duration probability shift obtained from the Ipswich Gage data to South Middleton, Fennessey constructed flow duration curves for the Ipswich River at the South Middleton Gage #01101500, with a contributing area of 44.5 square miles. The reproduced safe yield present and future state flow duration is shown in Figure 3. Up to this point, all three flow duration graphs generated from this analysis matched Fennessey's graphs found in the files. However, Fennessey's flood skimming flow duration curve for the South Middleton Gage was not able to be reproduced and indicate a data set or calculation error. At the WRC reference streamflow of 1.0 cfsm (44.5 cfs), the present day flow duration indicates 71% probability (Figure 4) versus Fennessey's flow duration result of 83% probability.

Further examination of South Middleton Gage data reveals a more fundamental predicament with the methodology. Instead of transposing Ipswich Gage results to South Middleton, the South Middleton data were run through the methodology calculation for average daily streamflow for July, August and September for 1980 and 1981 with very different results. The average daily streamflow for the 6-month period is 8.75 cfs. When the WRC minimum streamflow of 9.6 cfs (0.216 cfsm) is subtracted from 8.75 cfs, the result is negative, or zero basin yield for the upper basin. A zero basin yield rescaled to the entire watershed is still zero basin yield. The recently established 0.42 cfsm (18.7 cfs) threshold for the Ipswich Basin would result in a greater negative number for basin yield.

This finding indicates that according to the methodology, a basin yield obtained from one location in the basin may differ from that obtained in another location. At the very least, it means that with safe yield expressed as one number, the safe yield withdrawal may not be equally distributed throughout the basin as impacts are more likely in the basin headwaters. The methodology fails to allow for and distinguish between a basin yield for a head waters subbasin as opposed to the overall downstream watershed. When considering basin yield, the issue of scale matters. Thus one size does not fit all.

Why the safe yield method doesn't work.

There are several reasons why the safe yield method, as presently described, has proved ineffective, inaccurate and had to be abandoned. Detailed comments for each regulatory section are noted below, but the main reasons for the ineffectiveness of safe yield are:

- <u>Inadequate Method Assumptions and Definitions:</u> Given natural variability of streamflow, safe yield cannot be expressed as one number without regard to frequency, duration and basin location. An annually averaged daily water use consumptive loss rate is not an appropriate unit of measure to regulate withdrawals.

- Disputable Goal: Is the goal of safe yield to promote and protect an environmentally sustainable water source, or is it to promote an undefined balance between the environment and water withdrawals? We can't continue to play it both ways.

- Method Oversimplification: Use of streamflow analysis alone for safe yield determination fails to account for the complexity of hydrologic processes, particularly the interaction with groundwater. The method's approach is inconsistent with the definition of water source where surface and groundwater should be considered as one hydrologic unit. Shouldn't an aquifer yield be part of the basin yield? Furthermore, groundwater withdrawals can deplete an aquifer and basin yield. Finally, a stream flow duration curve, by itself, is an insufficient measure for safe yield.

- The Problem of Baseline: Where do we start? Do we start with natural streamflow with no withdrawals; 1986 baseline streamflow after registration but prior to permitting; or present day USGS stream gage measures, etc.? The starting point is critical to the safe yield determination. Recall that streamflow statistics evolve; the regulatory statistic 7Q10 value at USGS South Middleton gage under no withdrawals was simulated at 4.1 cfs, as compared to 0.54 cfs with average withdrawals through 1993. Today, in the Ipswich, the 7Q10 statistic could be less than 0.54 cfs.

- Failure to account for variability of streamflow by location and time.
  Safe yield determination used 1980-1981 drought stream data. But 1980-1981 drought levels varied in magnitude and timing throughout the state. Consequently, the universal application of the drought data plays out differently by location.

- Lack of justification for defining an acceptable degree of risk. While the method illustration demonstrated the probability shift (2.8% from present state to worse state flow duration for the Ipswich), there was no justification or significance associated with the 77% exceedence probability finding at the WRC minimum streamflow level. Are we to be concerned that all graphs indicate some degree of no flow? Ought not safe yield be concerned with physical, biological and chemical integrity of stream and aquatic habitat? Ought not safe yield be integrated with surface water quality standards for designated use as we establish an acceptable degree of risk?

- Method Validity and Reliability: There are technical deficiencies with validity and reliability. The method resulted in an Ipswich safe yield of 3.5 mgd. Since allocated permitted withdrawals are less than 3.5 mgd today, the Ipswich River should be sustainable and healthy; when, in fact, the Ipswich River is severely impacted by low flow. Therefore, the safe yield methodology is not valid since it does not measure what it purports to measure. The safe yield method is also not reliable. Different basin yield results (3.5 cfs vs. 0 cfs) were obtained from USGS gages in different locations within the same Ipswich Basin.

Further detail with specific questions and comments:

Definitions

- Safe yield definition connotes sustainability of a water source and does not distinguish between impacts from registered or permitted withdrawals.
- Floodskimming definition specifically denotes surface and groundwater. It is unclear how floodskimming applies to groundwater.

310 CMR 36.31(1): Department options for determining safe yield

- The Department *may* consider registered withdrawals for safe yield determination
- Water balance considering magnitude, frequency, duration, timing and scale should be investigated.
- How can one separate hydrologic impacts of proposed, existing and permitted withdrawals from registered withdrawals?

310 CMR 36.31(2): Surface water streamflow analysis and determination of safe yield.

- The methodology fails to take the interaction with groundwater and baseflow into account. The basin must be dealt with as one hydrological unit of surface and groundwater. How does one manage a water source, when the underlying aquifer(s) boundary is not coincident with the topographic watershed delineation?

  It must be noted that at the frequent, actual times of Ipswich River's dry streambed during summer months, the public water supply wells are still pumping full throttle. Although the water can no longer come from induced infiltration due to depleted streamflow, water withdrawals come from intercepting groundwater base flow, and the impacts to the environment extend to groundwater deficits with lowering the water table.
- Recognition that USGS stream data reflects impacted flow must be taken into account when using the data as baseline.
- How is it that the methodology assumes that all stream flow above the 1980-81' drought level, buffered with the WRC minimum streamflow, is acceptable for off-stream allocation? With allocation withdrawals permitted at this level, the river would be in a continual state of recovery.
- According to the methodology, since permitted withdrawals are within the determined 3.5 mgd safe yield, the assumption is that the Ipswich River is healthy and sustainable; when in fact, there is documented evidence that the Ipswich River is severely impacted by low flows and considered in a constant state of recovery. Consequently, the methodology is ineffective and not valid.
- Basin yield is far too complex to be reduced to a simple method with a single result. Basin yield must consider flow magnitude, frequency, duration, timing, location and scale.
- The methodology fails to take environmental criteria, like wetlands drawdown, aquatic habitat alteration, along with macroinvertebrates and fish requirements into account. Basin yield must also consider groundwater, along with physical, biological and chemical integrity for a healthy riverine ecosystem. Basin yield should also be connected to a river's designated class for water quality standards

(Class B waters for the Ipswich River), along with instream uses for fishing, swimming and recreation.

310 CMR 36.31(3): DEP shall use safe yield in constructing flow duration curves.

- A flow duration curve shows the percentage of time a specified discharge is equaled or exceeded. Flow duration is a cumulative frequency reflecting a probability of occurrence for a specified flow. While this measure is essential, the flow duration curve alone is not an appropriate measure to assess magnitude and duration for seasonal variation or low flow frequencies of recurrent intervals, let alone manage for daily withdrawals, and other measures must be sought.
- What is the significance when the flow duration curve for a present state condition at the WRC minimum streamflow level indicates a 77% probability? Is it a problem that 23% of the time the WRC minimum streamflow will not be attained? Is it acceptable when flow duration indicates a probability for no flow? What justifies the probability shift as an acceptable degree of risk?
- With one basin yield number, the method fails to take natural flow variation into account and fails to address the allocation distribution of basin yield relative to local impacts.
- The method is not internally consistent within a basin.

310 CMR 36.31(4): Floodskimming.

- With the Department's movement to streamflow thresholds throughout the year, the floodskimming season concept in the regulations is obsolete.

310 CMR 36.31(5): Consumptive loss and maximum allocation.

- Not withstanding the acknowledgement that USGS consumptive loses for land use categories need refinement, recognition must be given to the fact that percentage of land uses in a community change over time, so consumptive loss for that community changes with consequential implications for basin yield.
- What is the justification for taking a consumptive loss rate from an already impacted stream? The methodology fails to take local consumptive loses relative to local stream impacts into account. The consumptive loss rate protocol calculated for the communities in Table 2 needs to be re-evaluated.
- How do you reconcile an annually consumptive loss rate unit of measure with the natural streamflow variation?
- In determining water source sustainability, what is the justification for only looking at permitted withdrawals and not registered withdrawals?

Summary and Conclusion

In summary, there are several reasons for the failure of DEP regulatory safe yield as a management tool in support of sustainability of a water source. The collapse of WRC/DEM's Basin Plans with minimum streamflow was fundamental, because minimum streamflow was part of safe yield and DEM had instructed DEP on what baseline data (1980-1981) was to be used for the determination of safe yield. In hindsight, DEM has since recognized the issue of starting point baseline and where do you begin. Streams in Massachusetts are highly regulated and USGS stream gages reflect impacted flow. Precipitation and streamflow proved to be too variable for basin planning calculations for minimum streamflow because 1980-1981 drought levels varied in magnitude and timing throughout the state. By 1992, it became evident to WRC/DEM that basin planning overestimated water availability and underestimated mimimum streamflow as protective of habitat.

DEP's safe yield was dependent on basin planning and the flaws of that effort carried forth to the safe yield methodology. The methodology's failure to incorporate the interaction between surface and groundwater as a hydrologic unit is also fundamental. The methodology fails to embrace the notion that safe yield of a water source does not distinguish between impacts from registered or permitted withdrawals. Furthermore, given the dynamic complexities of streamflow, the interaction with groundwater, and natural variability of streamflow, safe yield cannot be oversimplified to a single number for water allocation management purposes or instream habitat protection, and the method for safe yield determination cannot be reduced to one mathematical subtraction or a flow duration curve.

While the safe yield methodology may have served the Water Management Program in its initial program stages, serious concerns for method validity, reliability and other deficiencies require reconsideration. The task then was considerable; the task now is more extensive. With the benefit of increased knowledge and understanding of streamflow from several recent USGS studies, the complexities of determining safe yield are better understood, but a safe yield determination still remains elusive. Nevertheless, with the purpose of the Water Management Act Regulations to balance competing interests of water withdrawals with instream and other uses at stake, safe yield must be re-examined and an improved method for its determination be developed.

Figure 1.

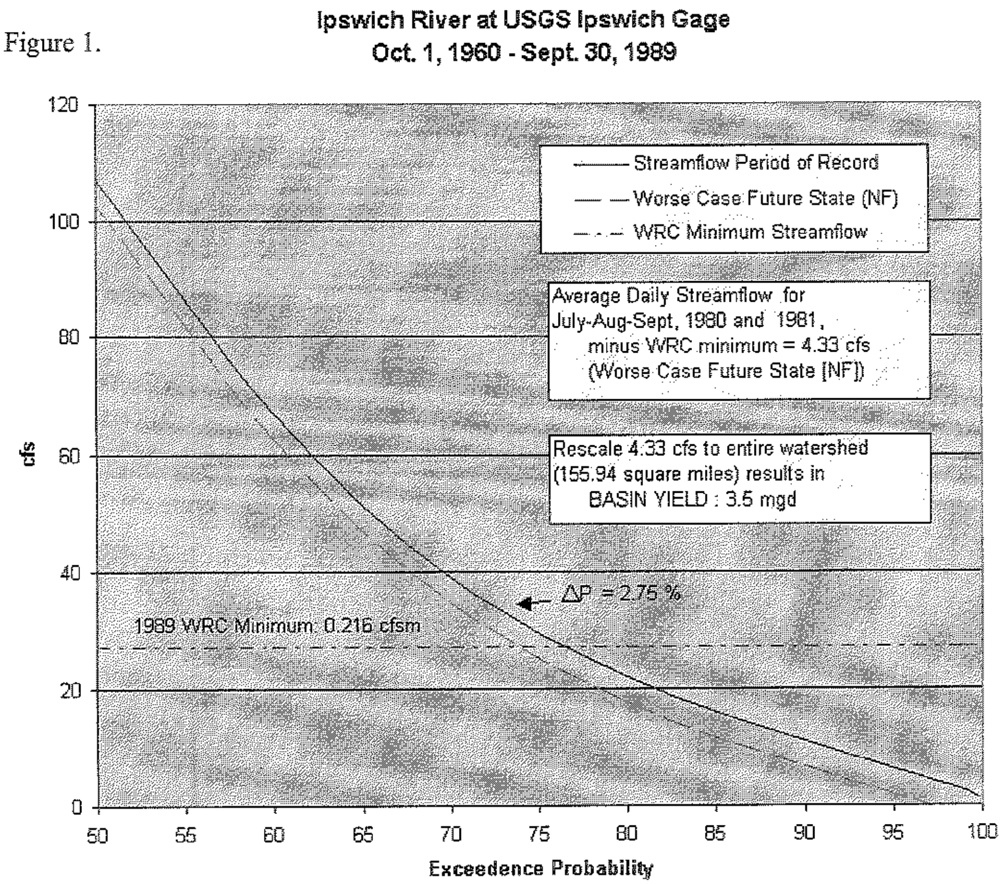

Figure 2.

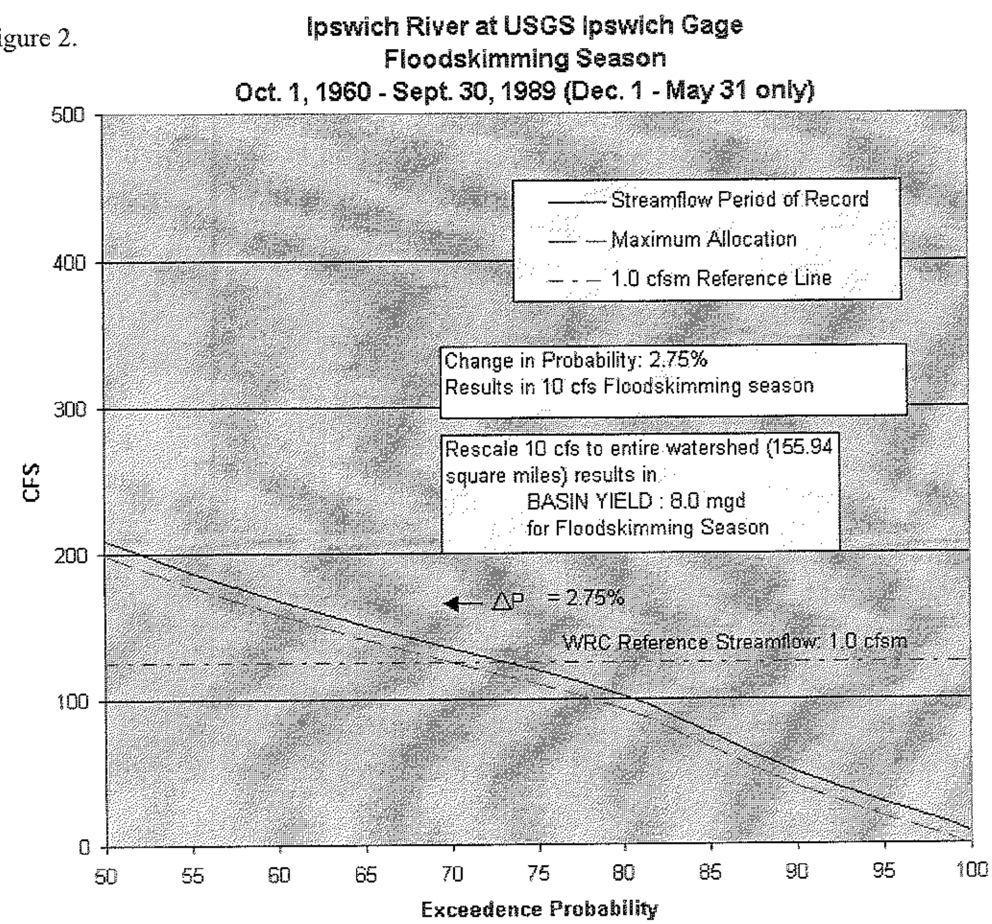

Figure 3.

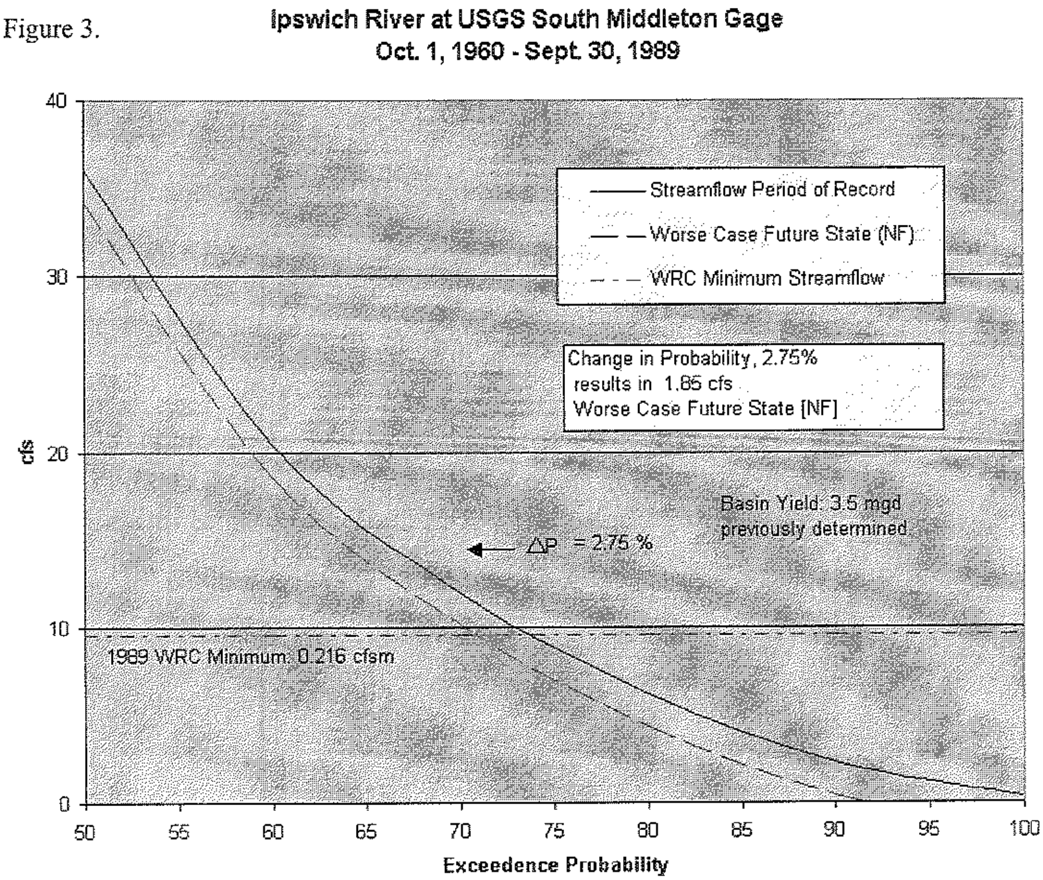

Figure 4.