STREAM SYSTEMS TECHNOLOGY CENTER

# STREAM NOTES

To Aid in Securing Favorable Conditions of Water Flows

**October, 1998**

## Calculated Risk: A Tool for Improving Design Decisions

All projects and activities designed for the future have elements of risk and uncertainty associated with them. Hydrologic uncertainties include many unknowns that may affect a designed project and contribute to its success or failure. While there are areas of uncertainty that are unpredictable based on historical events, the prudent designer can calculate some risks by using historical information about rainfall and runoff probability in the design of erosion control and hydraulic structures.

For purposes of this discussion, uncertainty is when the potential outcome cannot be estimated based on historical events. These uncertainties can only be addressed in a broad sense. Risk, on the other hand, is the calculated likelihood of an unacceptable event occurring. While the exact sequence of streamflow or rainfall events for future years cannot be precisely predicted, much is known about the probable variation of future streamflows and rainfall based on past observations. The probability of these hydrologic events can therefore, be predicted assuming that the future behaves like the past. The use of probability allows the designer to use calculated risk as a rational tool in making design decisions.

A frequency analysis of discharge or rainfall data is commonly used to predict, based on past records, the frequency that the magnitude of an event will be equaled or exceeded. Information about the frequency that storms or runoff events of a given size and/or intensity will be equaled or exceeded annually is especially useful for designing structures such as culverts, bridges, or erosion control treatments.

If the data includes many years, the event that is expected to be equaled or exceeded once every *n* years, **on average**, can be predicted. The frequency of occurrence of an individual annual event is referred to as the average return period, or recurrence interval, expressed in years. For example, a 10-year flood, on average, should be equaled or exceeded only 10 times in 100 years, or one time in ten years. A return period, however, does not imply regularity in occurrence; rather, events will occur at random intervals following the laws of probability. Also, the return period fails to address cumulative probability over a period of years.

The traditional approach to sizing structures, such as culverts, relies heavily on annual recurrence intervals. For example, major culverts and minor

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*The* PRIMARY AIM *is to exchange technical ideas and transfer technology among scientists working with wildland stream systems.*

CONTRIBUTIONS *are voluntary and will be accepted at any time. They should be typewritten, single-spaced, and limited to two pages. Graphics and tables are encouraged.*



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bridges are frequently designed to pass the 25-year flood and checked for a 50-year flood. Large bridges are generally designed to pass a 50-year flood and checked for a 100-year flood. This approach, based primarily on the annual recurrence interval of the flood event, fails to adequately consider the cumulative risk of failure over the life of the structure.

The annual recurrence interval indicates only the **average interval** between events equal to or greater than a given size. Managers need to focus on the **calculated risk**, considering the design life of the project and the desired chance of success. These variables allow calculation of the equivalent annual recurrence interval storm or runoff event that satisfies the design life and risk criteria.

Selecting the design recurrence interval should only occur after management has defined the amount of acceptable risk. The risk of failure depends on both the annual recurrence interval and the design life. The acceptable risk should also incorporate other concerns including the anticipated economic and environmental hazards associated with failure. **The key factor to consider in determining the amount of risk to tolerate are the consequences if the structure (e.g., culvert or bridge) should fail during the design life.**

In this article, we present one equation that shows the interrelation between probabilities, recurrence intervals, and the risk associated with various design life periods. For a rigorous treatment of probability, consult any standard hydrology reference. The equation used is the foundation for the Calculated Risk Table and the Calculated Risk Diagram on the following pages. The information contained in the table and plotted on the diagram is the same; the only difference is how the data is displayed.

The following equation calculates the chance that the capacity of a structure will be equaled or exceeded during its lifetime of *n* years. For simplicity, exceeding capacity is referred to as failure. The probability ($p_n$) that a given event will be equaled or exceeded **at least once** in the next *n* years is the sum of the probabilities of occurrence for each year to the $n^{th}$ year. Expressing probabilities in terms of recurrence intervals results in a geometric progression that reduces to:

$$p_n = 1 - \left[\frac{T_r - 1}{T_r}\right]^n$$

where $p_n$ = probability of occurrence, $T_r$ = recurrence interval in years, and $n$ = design life in years.

For example, assume a culvert has capacity to pass the 25-year flow event. The probability that the structure's capacity will be equaled or exceeded during the next 5 years (i.e., the chance of failure), is computed as:

$$p_n = 1 - \left[\frac{25 - 1}{25}\right]^5 = 1 - (0.96)^5 = 1 - 0.82 = 0.18$$

In other words, there is a 18% chance that the design event, the 25-year flood, will be equaled or exceeded in the next 5 years. In this example, designing for the 25-year event means that management is willing to accept roughly a 20% chance of failure over a 5 year time period. Failure in this context means simply that the design event will probably be exceeded.

The Calculated Risk Table and Diagram can be used to analyze a wide range of potential risk scenario questions.

# CALCULATED RISK TABLE (Recurrence Interval in Years)

## RISK - PERCENT CHANCE

DESIGN LIFE (IN YEARS)

| Success | 95 | 90 | 85 | 80 | 75 | 70 | 65 | 60 | 55 | 50 | 45 | 40 | 35 | 30 | 25 | 20 | 15 | 10 | 05 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Failure** | **5** | **10** | **15** | **20** | **25** | **30** | **35** | **40** | **45** | **50** | **55** | **60** | **65** | **70** | **75** | **80** | **85** | **90** | **95** |
| **1** | 20 | 10 | 7 | 5 | 4 | 4 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| **2** | 40 | 20 | 13 | 10 | 8 | 6 | 5 | 5 | 4 | 4 | 4 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 |
| **3** | 59 | 29 | 19 | 14 | 11 | 9 | 8 | 7 | 6 | 5 | 4 | 4 | 3 | 3 | 3 | 2 | 3 | 2 | 2 |
| **4** | 78 | 39 | 25 | 19 | 15 | 12 | 10 | 8 | 7 | 7 | 6 | 5 | 4 | 4 | 4 | 3 | 3 | 2 | 2 |
| **5** | 98 | 48 | 32 | 23 | 18 | 15 | 13 | 10 | 9 | 8 | 7 | 6 | 6 | 5 | 4 | 4 | 3 | 3 | 2 |
| **6** | 117 | 58 | 38 | 28 | 22 | 17 | 15 | 12 | 11 | 10 | 8 | 7 | 7 | 6 | 5 | 4 | 4 | 3 | 2 |
| **7** | 136 | 67 | 44 | 32 | 25 | 20 | 17 | 14 | 12 | 11 | 9 | 8 | 7 | 6 | 6 | 5 | 5 | 4 | 3 |
| **8** | 156 | 77 | 50 | 37 | 28 | 23 | 20 | 16 | 14 | 12 | 11 | 9 | 8 | 7 | 7 | 5 | 5 | 4 | 3 |
| **9** | 175 | 86 | 56 | 41 | 32 | 26 | 22 | 18 | 16 | 13 | 12 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 4 |
| **10** | 195 | 96 | 63 | 46 | 35 | 29 | 24 | 20 | 17 | 15 | 13 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 |
| **11** | 214 | 104 | 69 | 50 | 39 | 31 | 27 | 22 | 19 | 16 | 14 | 13 | 11 | 10 | 9 | 7 | 6 | 5 | 4 |
| **12** | 234 | 114 | 75 | 55 | 42 | 34 | 29 | 24 | 21 | 18 | 16 | 14 | 12 | 10 | 9 | 8 | 7 | 6 | 5 |
| **13** | 254 | 124 | 81 | 59 | 46 | 37 | 31 | 26 | 22 | 19 | 17 | 15 | 13 | 11 | 10 | 9 | 7 | 6 | 5 |
| **14** | 273 | 133 | 86 | 64 | 49 | 40 | 34 | 28 | 24 | 21 | 18 | 16 | 14 | 12 | 11 | 9 | 8 | 7 | 5 |
| **15** | 293 | 143 | 93 | 68 | 53 | 43 | 36 | 30 | 26 | 22 | 19 | 17 | 15 | 13 | 12 | 10 | 8 | 7 | 6 |
| **16** | 312 | 152 | 99 | 73 | 56 | 45 | 38 | 32 | 27 | 24 | 20 | 18 | 16 | 14 | 12 | 10 | 9 | 8 | 6 |
| **17** | 332 | 162 | 105 | 77 | 60 | 48 | 40 | 34 | 29 | 25 | 22 | 19 | 17 | 15 | 13 | 11 | 9 | 8 | 6 |
| **18** | 351 | 171 | 111 | 82 | 63 | 51 | 43 | 36 | 31 | 26 | 23 | 20 | 18 | 15 | 14 | 12 | 10 | 8 | 7 |
| **19** | 371 | 181 | 117 | 86 | 67 | 54 | 45 | 38 | 32 | 28 | 24 | 21 | 19 | 16 | 14 | 12 | 11 | 9 | 7 |
| **20** | 390 | 190 | 123 | 91 | 70 | 57 | 47 | 40 | 34 | 29 | 26 | 22 | 20 | 17 | 15 | 13 | 11 | 9 | 8 |
| **25** | 488 | 238 | 154 | 113 | 88 | 71 | 59 | 50 | 42 | 36 | 32 | 28 | 25 | 22 | 19 | 16 | 14 | 11 | 9 |
| **30** | 585 | 285 | 185 | 135 | 105 | 85 | 71 | 60 | 51 | 44 | 38 | 33 | 29 | 25 | 22 | 19 | 16 | 14 | 11 |
| **35** | 683 | 333 | 216 | 157 | 122 | 99 | 82 | 70 | 59 | 51 | 45 | 39 | 34 | 30 | 26 | 23 | 19 | 16 | 12 |
| **40** | 780 | 380 | 247 | 180 | 140 | 113 | 94 | 79 | 68 | 58 | 51 | 44 | 39 | 34 | 29 | 25 | 22 | 18 | 14 |
| **45** | 878 | 428 | 277 | 202 | 157 | 127 | 105 | 89 | 76 | 66 | 57 | 50 | 43 | 38 | 33 | 28 | 24 | 20 | 15 |
| **50** | 975 | 475 | 308 | 225 | 174 | 141 | 117 | 99 | 85 | 73 | 63 | 55 | 48 | 43 | 37 | 32 | 27 | 22 | 17 |
| **60** | 1170 | 570 | 370 | 269 | 209 | 169 | 140 | 118 | 101 | 87 | 76 | 66 | 58 | 50 | 44 | 38 | 32 | 27 | 20 |
| **70** | 1365 | 665 | 431 | 314 | 244 | 197 | 163 | 138 | 118 | 101 | 89 | 77 | 67 | 59 | 51 | 44 | 37 | 31 | 24 |
| **80** | 1560 | 760 | 493 | 359 | 279 | 225 | 186 | 157 | 134 | 116 | 101 | 88 | 77 | 67 | 58 | 51 | 43 | 35 | 27 |
| **90** | 1755 | 855 | 554 | 404 | 313 | 253 | 209 | 177 | 151 | 130 | 113 | 99 | 86 | 75 | 66 | 57 | 48 | 40 | 31 |
| **100** | 1950 | 950 | 616 | 449 | 348 | 281 | 233 | 196 | 168 | 145 | 126 | 110 | 96 | 84 | 73 | 63 | 53 | 44 | 34 |

**Example:** If a culvert through a road is to last for 20 years with a 25% chance of failure (or a 75% chance of success), the culvert should be designed for the 70-year flood recurrence event. Failure in this context means that the the recurrence interval flood is equalled or exceeded **at least once** during the specifie design life. The culvert may or may not physically fail or be washed out.

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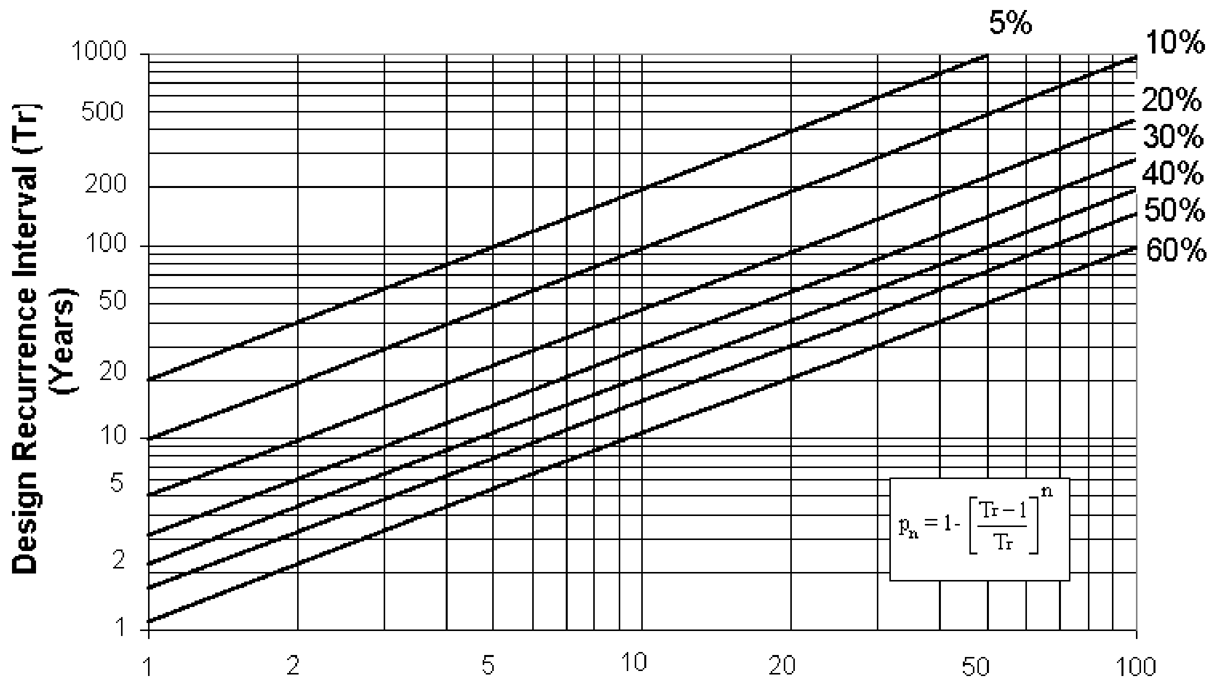
## Calculated Risk Diagram

### Theoretical Probabililty (in percent) of Equaling or Exceeding a Design Recurrence Interval for Various Periods of Design Life




The table is best used to calculate the equivalent recurrence interval associated with various levels of risk and design periods. For example, suppose management wants a 75% chance of success for a road culvert over 20 years. Looking at the table, it is evident that the culvert should be designed for the 70-year flood recurrence event.

Suppose a culvert has been designed for a 50-year flood event, what is the probability of failure over a 20 year period? By entering the table at a design life of 20 years and moving right to a recurrence interval of 50 years (between 47 and 57 in the table), one can see that 50 years falls between a 70% to 65% chance of success. The same information can be obtained from the graph or computed directly using the provided equation. The computed chance of failure in this case is 33% (equivalent to a 67% chance of success).

It is important for managers to select the desired degree of success rather than to focus simply on the return period when making design decisions.

Calculated risk tools provide a means to evaluate alternative risk scenarios. Remember that the cost of little risk (i.e., close to 100% certain) can be prohibitively high because of the exponential nature of the equation. For example, a 95% certainty that a culvert will not fail over a 20 year period, requires designing for almost a 400-year flood event. Consequently, managers must be realistic and prudent when establishing risk objectives.

For practical examples of how to use risk, recovery period, and recurrence interval interactions to design erosion control treatments following wildfire see:
**Schmidt, Larry J.,** 1987. Calculated risk and options for controlling erosion. Proc. Conf. XVIII, International Erosion Control Assc., Reno, NV, Feb. 26-27, pp. 279-283.
Request a copy of the paper by sending an e-mail to:
stream/rmrs@fs.fed.us

# FISP - The Federal Interagency Sedimentation Project

Do you need sediment sampling equipment? Would you like to know how many different kinds of samplers are available for sampling suspended sediment or bedload? Would you like to buy a gravelometer (US SAH-97 hand-held size analyzer)? Do you need bottles or caps for your US DH-48 sampler? Did someone drive over your wading rod and bend it? For help with things related to sample sediment equipment, see the Federal Interagency Sedimentation Project's (FISP) Web page at:

**http://fisp.wes.army.mil/**

FISP was created in 1939 to unify the research and development activities of Federal agencies involved in fluvial-sediment studies. Research conducted by FISP originally focused on hydraulic and mechanical aspects of sediment sampling but has expanded to include development of sample-analysis methods, automatic in-situ analyzers, and sampling techniques and equipment for sampling water quality in streams and rivers. The equipment and techniques of FISP are the standards used by most Federal, State, and local governments, and private organizations collecting sediment samples in the United States.

FISP is funded and staffed by the Federal government and is only authorized to sell items to Federal, State, and local governmental agencies of the United States, and to Federal and State educational institutions.

FISP's Web page contains a catalog of equipment available from the project along with a brief description, a price list, and ordering instructions. If you need sediment sampling equipment, are curious about FISP's activities, or are simply curious about the various designs that have been developed, check it out.

**FISP**™ ***Federal Interagency Sedimentation Project***

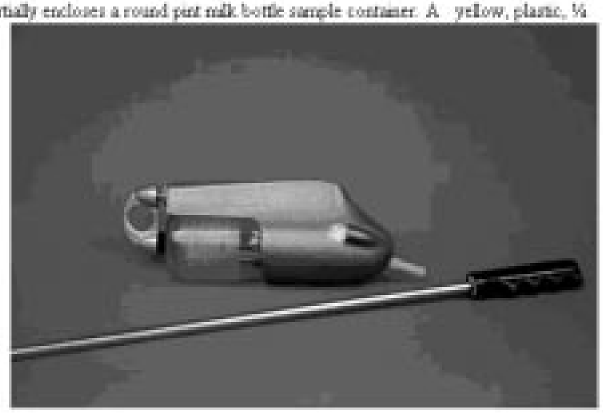
FISP Home Page Price List Catalog Index

***US DH-48 Depth integrating suspended wading type sampler***

**part number: 001010**

The US DH-48 is a lightweight sampler used for collection of suspended sediment samples where wading rod sampler suspension is used.

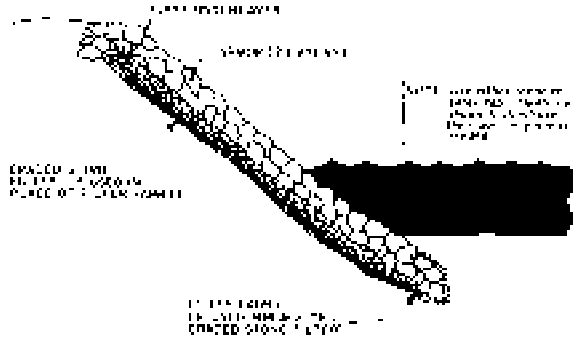
The sampler consists of a streamlined aluminum casting, 13 inches long, which partially encloses a round pint milk bottle sample container. A yellow, plastic, ¼ inch (0.64 cm) intake nozzle extends horizontally from the nose of the sampler body. A streamlined projection, pointing toward the rear on the side of the sampler head, accommodates the air exhaust port from which air may escape from the bottle as the sample is being collected.



A standard, ½ inch diameter wading rod (not furnished) is threaded into the top of the sampler body for suspending the sampler. The sample container is held in place and sealed against a rubber gasket by a hand operated, spring tensioned clamp at the rear of the sampler. The instrument can sample to within 3½ inches of the streambed.

A copy of operation instructions, Report J, is furnished with each purchased sampler.

# Ask DOCTOR Hydro



Typical riprap bank protection cross-section.
Adapted from: U.S. Army Corps of Engineers, 1981.
Low Cost Shore Protection: A Guide for Engineers and Contractors.

**Dear Doctor Hydro: A notable stream restoration consultant has suggested that riprap bank protection is more stable if the material is uniform-grade rather than well-graded. The argument is that at high flow velocities (shear stress), the smaller particles of the well-graded riprap may pop out and destabilize the larger ones. Since highway departments frequently use the latter specification, what does Doc Hydro think?**

In the past, some investigators have reasoned that well-graded riprap (a wide range of sizes in the mixture) would perform better than uniform-grade riprap (all rocks about the same size) due to the spaces between large rocks filling with smaller ones which provides added stability. Many design manuals, including the U.S. Army Corps of Engineers manual, encourage this approach.

Current thinking, however, is that the more uniform riprap provides greater stability. This conclusion is supported by several studies (Wittler and Abt, 1990; Abt et al., 1988; Maynord, 1988; Anderson et al., 1968). Wittler and Abt postulated that the greater stability of uniform riprap is due to more efficient transfer of stress than occurs in well-graded riprap. A more uniform bearing stress between similarly sized particles and the transfer of loads through the centers of the particles rather than tangentially are given as reasons for the greater stability. The study also concluded, however, that failure of uniform-grade riprap is more sudden than well-graded riprap.

The referenced studies considered the effect of gradation on stability with all other factors being equal. **Failure of riprap installations are often due to other factors such as insufficient toe-down depths, not keying in the leading and trailing edges of the revetment, or not providing an underlying filter.** Also, the angularity of the rock is important when considering stability as this provides a greater degree of interlocking between particles, which makes the rocks harder to dislodge.

Another factor to consider is the impact of gradation on filter requirements. A filter is a layer or layers of gravel, small stone, or geotextile (filter fabric) placed between the underlying soil and the rock protection. The filter layer prevents migration of fine particles through the voids in the overlying rock and permits relief of fluctuating hydrostatic pressures. Depending on the size of the riprap compared to the size of the underlying soil, a filter may sometimes be omitted. However, uniform-grade riprap with a lack of smaller particles to fill the interstitial voids is more likely to require a filter than a well-graded mixture. In addition, if a granular filter is used, the smaller sizes of the riprap gradation must properly interface with the larger sizes of the filter. Consequently it is difficult to use large uniform riprap, and economically interface it with a granular filter. With geotextiles this is not a problem, but a granular-bedding layer is sometimes used on top of the geotextile to prevent damage from placing the riprap, especially when using large, angular rock.

In summary, all other factors being equal, uniform-grade riprap is preferred over well-graded riprap. However, uniform riprap generally costs more than well-graded riprap and other design criteria often are important in the success or failure of a riprap installation.

**References:**


Abt, S.R., Wittler, R.J., Ruff, J.F., LaGrone, D.L., Khattak, M.S., Nelson, J.D., Hinkle, N.E., and D.W. Lee, 1988. Development of Riprap Design Criteria by Riprap Testing in Flumes: Phase II. U.S. Nuclear Regulatory Commission, NUREG/CR-4651, Washington, DC., May 113.

Anderson, A.G., Paintal, A.J., and J. T. Davenport, 1968. Tentative Design Procedure for Riprap Lined Channels. Saint Anthony Falls Hydraulic Lab., Project Report. No.96, University of Minnesota, Minneapolis, MN.

Maynord, S.T., 1988. Stable Riprap Size for Open Channel Flows. Technical Report U.S. Army Corps of Engineers, HL-88-4, Waterways Experiment. Station, Vicksburg, MS.

Wittler, R.J. and Abt, S.R., 1990. The Influence of Uniformity on Riprap Stability. Hydraulic Engineering, Vol. 1, Proceedings of the 1990 ASCE National Conference, San Diego, CA, July 30 - August 3, pp. 251-265.



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## Chronicle of Instream Flow Activities

USGS science for a changing world IFIM

The River System Management Section (RSMS) within the Midcontinent Ecological Science Center, formerly part of the National Biological Survey, is now part of the Biological Resources Division of the U.S. Geological Survey. Many may recognize these folks as the Instream Flow Group of the U.S. Fish and Wildlife Service; developers of the Instream Flow Incremental Method (IFIM). The mission of RSMS is to provide information and technology for water resource management and environmental decision makers to conserve and enhance river/reservoir ecosystems.

One of the activities of RSMS is publication of the newsletter, ***Chronicle of Instream Flow Activities***. With the advent of the World Wide Web and the ever increasing cost of postage, ***Chronicle*** is now published only on the Web. ***Chronicle*** will address recent developments in all aspects of instream flows such as assessment methods, software updates, announcement of significant events, and notification of IFIM-related courses. The current issue of ***Chronicle*** is on the River Systems Management Section home page at:

**http://www.mesc.usgs.gov/rsm**

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# STREAM NOTES

**Editorial Policy**

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Please submit typed, single-spaced contributions limited to 2 pages. Include graphics and photos that help explain ideas.