Framing the Question: Challenges in Probabilistic Monitoring of Kansas Streams

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Photo by EF Smith

Photo by MS Cringan

Kansas has more landscape diversity than some realize.

Far left: North Fork of the Ninnescah, a naturally sandy-bottomed river in the Central Great Plains.

Immediate left: Palmer Creek, a high-gradient, rocky-bottomed stream in the Flint Hills.

An Unusual Sample Frame

The Kansas Surface Water Register

The target population for assessment comprises all classified stream segments of the state. These are delineated in the Kansas Surface Water Register (KSWR). In effect, the target population is congruent to the sample frame.

Use of the KSWR. In 1994, KDHE promulgated revised water quality standards, adopting by reference the newly developed Kansas Surface Water Register (KSWR). The Register has been used as the basis for 305(b) reporting on the status of the waters of the state since 1996 (KDHE 2006A).

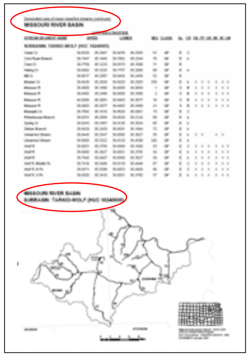
History of the KSWR. The Register was constructed in 1994 to meet requirements of the cooperative agreement between KDHE and EPA for the purpose of water quality standards implementation. The original 1994 Register was derived from the US EPA Reach File Version 3.0. In Spring 1994, all RF2 level features (that is, all waterbodies and segments that had proper names in the Geographic Names Information System) were selected from this dataset to form the first KSWR; this included both perennial and intermittent segments. In 1999, the KSWR was reconstructed on the newly available National Hydrography Dataset, a cooperative EPA-USGS surface water map coverage.

Structure of the KSWR. The Register is a map-and-list directory that explicitly defines the classified surface waters of the state. It includes about 2,500 lakes, wetlands, and stream segments. Each stream segment is identified as channel unit segment (CUSEGA), named using the applicable 8-digit HUC plus a one- to four-digit segment identifier. Each CUSEGA comprises one or more complete segments from the 1:100K NHD and includes any NHD segment that falls at least partly within the Kansas border. The newest official edition of the KSWR (KDHE 2006B) includes 2106 stream segments representing 29,774 stream miles.

Maintenance of the KSWR. The Register is maintained and published by the Use Assessment and Data Management Sections, subject to review and approval by EPA and the public.

Policy impacts on the KSWR. In 2001, Kansas Governor Bill Graves signed into law a bill that essentially changed definitions for classification and use designation of streams (Substitute for Senate Bill 204, K.S.A. 2001 Supp. 82a-2001). Special attention was given to low-flow streams, and the state contracted with USGS to develop a model to provide flow estimates for every stream segment on the KSWR (Perry *et al.* 2002). With impetus and funding from this legislation, the Use Assessment Section dramatically expanded its workforce and is on schedule to complete Use Attainability Analyses for all uses on all KSWR stream segments by 31 December 2007.

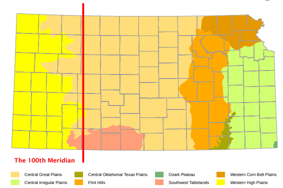
Below: an excerpt from the Kansas Surface Water Register.



The challenge. Monitoring is not optional; we are required to assess the full mileage of the KSWR. Because the sample frame is maintained by the Use Assessment and Data Support sections, we must work closely with them to anticipate how changes to the Register will affect our ability to generate unbiased assessments of conditions in Kansas streams. We must also report accurately on our knowledge of even those streams we are unable to sample (due to temporary lack of water or lack of permissions) – they are still part of the target population.

A Heterogeneous Resource

Dramatic climate gradient across a diverse landscape



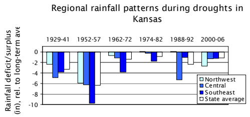
Experience teaches that it is not wise to depend upon rainfall where the amount is less than 20 inches annually. The isohyetal or mean rainfall line of 20 inches...in a general way...it may be represented by the one hundredth meridian. [In this region] agriculturalists will early resort to irrigation.
—John Wesley Powell, 1878

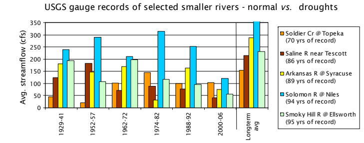
In the late 1800s, John Wesley Powell first noted the stark contrasts in precipitation at the 100th meridian. This longitude represented "the boundary between the moist east and the arid west" (Rosenberg 2007). To the east of this line, the average annual precipitation exceeds twenty inches and irrigation is not critical for agriculture. To the west of the 100th Meridian, however, where rainfall is less abundant and reliable, crop production is largely dependent on irrigation. In Kansas, normal annual precipitation ranges from about 19" in the southwest to over 38" in the southeast, and this gradient falls across a heterogeneous landscape.

In Kansas there are eight Omernik Level-III ecoregions (Chapman et al. 2001). The Western High Plains, located in far western Kansas, is typical of land beyond the 100th Meridian. It receives less than 20 inches of precipitation annually, is considered arid to semi-arid, and relies heavily on groundwater for irrigation. Many streams are intermittent or ephemeral, though this may not always have been the case (Angelo 1994). Just to the east, the Central Great Plains is slightly lower in elevation, receives more precipitation, and has a less regular topography. This ecoregion covers the greatest land area in Kansas is predominantly farmland that represents the country's major winter wheat growing area. Low gradient streams in this region are typically sandy-bottomed or silty. Further to the east lie the Flint Hills, which contain the largest intact tallgrass prairie on the continent. This region is characterized by rolling hills, rangeland, and humid summers, as well as higher-gradient rocky-bottomed streams. The other five ecoregions in Kansas are the Central Irregular Plains, Western Corn Belt Plains, Central Oklahoma/Texas Plains, Ozark Highlands, and Southwestern Tablelands.

Conditions currently exacerbated by drought

Kansas has a long history of drought. The most notable was the "Dust Bowl" of 1929-41; however, there have been other instances in the past century (*i.e.* 1952-57, 1962-1972, 1974-1982, 1988, and 2000 to present). Drought entails not only reduced precipitation, but also the combined effect of sunlight, humidity, temperature, wind, and human and other biotic impacts. The effect of the current drought (2000 to present) on stream flow level has in many instances resulted in record low stream flow conditions. These record lows have occurred despite higher average precipitation than during the "Dust Bowl" (USGS 2007). Decreased flows may be related to groundwater depletion and agricultural practices (Sophocleous 1998).





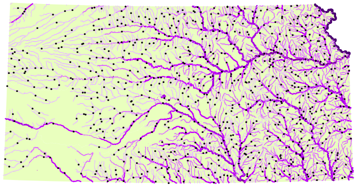
Stream flows are lower now than they were in earlier droughts, even though rainfall deficits are not as extreme.

All drought and flood data in above graphs are from USGS (2007) and references cited therein. Period of record for "normal" is 1971-2000. Long-term average for Solomon River is 552 cfs.

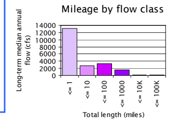
An Unique Survey Design

Unstratified and unweighted

A program intended to enhance knowledge of smaller streams



The 800 candidate sites of Survey Design A. The KSWR "flow classes" shown here are based on long-term estimated median annual flow from Perry *et al.* (2002)



Over 40% of the stream mileage on the Kansas Surface Water Register, and thus the same proportion of our candidate sample sites, have an estimated long-term median flow of ≤1 cfs.

Established monitoring programs. Until 2006, data from two established stream monitoring programs supported the agency's biennial 305(b) stream assessment, 303(d) listing of impaired waters, and follow-up monitoring for watershed management. These two programs, the Stream Biology Program and the Stream Chemistry Program, have traditionally focused their sampling on a network of targeted stations. These perennial sites have been carefully selected to serve as watershed integrator sites, reference sites, or pollution monitoring sites. The 100 stations of the Biology program and the 320 stations of the Chemistry program, sampled by a combined staff of six personnel, have done an excellent job of monitoring watersheds and larger waterways of the state. These programs captured only limited data from smaller-order streams, however, and there was some question about potential for bias. At the same time, these two programs continue to face increasing demands for follow-up sampling for watershed planning. Kansas' active watershed planning program has written over 1,200 EPA-approved TMDL (Total Maximum Daily Load) plans since 2000.

Birth of the probabilistic program. Over 80% of the stream mileage on the Register has an estimated long-term median flow of 10 cfs or less. The agency has long recognized the need to monitor lower-order streams on the Register, but until recently lacked the capacity to do so. Not long ago, the agency published a five-year monitoring strategy that called for the establishment of a probabilistic program (KDHE 2005). Soon after, funding became available to establish the program, which currently has three full-time staff.

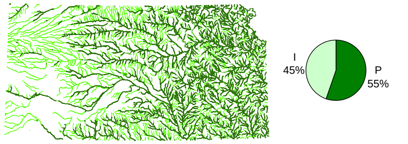
An unweighted survey design. The first survey design was produced in February 2006. The design calls for fifty new sites each year, with 200 points (four years) contributing to each assessment period. It includes a generous oversample to compensate for dry sites and landowner denials. With 800 candidate sample points, it should easily provide for four years of sampling. The design is unweighted, which means that every point on the KSWR stream network is equally likely to be selected for sampling. Most other states weight their survey designs toward higher-order streams.

Estimates of intermittency

We know that a significant proportion of Kansas stream mileage is intermittent, but we have not established a definitive value. Below are estimates based on four data sources.

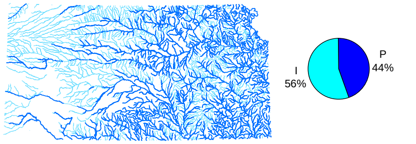
1. Cartographic estimate of intermittent mileage

Based on USGS 1999 Digital Line Graphs interpreted from original 1:100K hand-drawn maps. Intermittent streams are those represented as the "610/dotted-line" class of river segments; the remainder are perennial (USGS 1998).



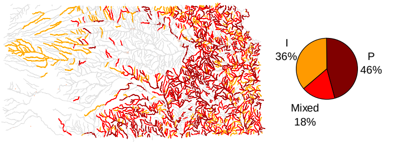
2. Flow-model estimate of intermittent mileage

Based on USGS extrapolated flow estimates (Perry *et al.* 2002). Perennial streams are represented as all segments with long-term P75 estimated to be greater than 0 cfs at the lower terminus. This criterion is based on a definition of "permanent and semi-permanent" streams that normally flow at least 9 months of the year (Boulton *et al.* 2000).



3. UAA Empirical estimate of intermittent mileage

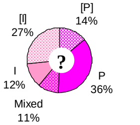
Based on Use Assessment Section's field observations of streams at selected access points, 2001-2005. Perennial streams are represented as all those segments scored as perennial at every access point; ,ntermittent are those scored as intermittent at every point, and Mixed are those that had at least one perennial and at least one intermittent score. Note that not all data were available at the time this summary was created (39% of data were not yet available in electronic form; these segments are depicted in grey).



4. Probabilistic estimate of intermittent mileage

We anticipate that data from the Stream Probabilistic Monitoring Program will support an unbiased estimate of what proportions of mileage on the Kansas Surface Water Register are perennial, intermittent, and ephemeral/dry. Quarterly sampling of chemistry sites will provide a reasonable temporal snapshot of annual flow conditions. Over time, these estimates may also form the basis for measuring large-scale trends in flow status of our stream network.

At right: Preliminary results based on the first year of chemistry site sampling attempts (n=85 sites). Sites scored "P" are those that had flowing water at all sampling events; those scored "I" were pooled or dry during all sampling events, and those scored "Mixed" had at least one flowing and one pooled/dry event. Sampled sites are solid (n=50); those not sampled due to lack of permission are hatched in white (n=35). Values for non-sampled sites [shown in brackets] are inferences based on desk and field reconnaissance.



Permissions

We're #1!

Gaining access on privately owned land is a not a trivial task, and there is always potential for bias arising from permissions issues.

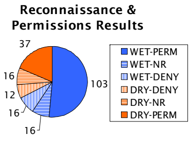
Laws and Site Access. Although specific state laws may be complex, most Western states follow the Prior Appropriation doctrine of stream ownership, based on Spanish law, whereas most Eastern states follow the Riparian doctrine, based on English law (Apple 2004). In addition to dictating what landowners may or may not do with the water from non-navigable streams that flow through their property, these doctrines also affect site access issues. In Riparian states, one may generally enter at a public access point and travel along the streambed to the desired site. In Appropriation states, such as Kansas, the streambed belongs to the landowner, and the sampler must identify the owner and then secure permission in order to access sites.

Kansas is #1. All states have some publicly owned (Federal/State) land, which can facilitate access. As of 1995, about 89% of Alaska's land was public, ranking it #50 among states in percent of land owned by private individuals. At the same time, about 1% of Kansas' land was in public ownership, ranking it NUMBER ONE among all states in terms of percent of land area under private ownership... Wow! (NRCM 2000).

Potential for bias. In an ideal probabilistic world, the sites actually sampled would be an unbiased subset of all candidate sites identified. But the potential for bias based on landowner denial/nonresponse must be considered. This may especially be the case where landowners are cautious in their interactions with what they perceive to be regulatory entities (Lesser 2001). Based on our agency's experience with the permissions process for the EPA National Wadeable Streams project in 2004, where access was denied on 16/31 Kansas sites (52%), we expected to gain permission on only about half of our candidate sites. We had no expectations as to whether the "permission" sites would be representative of the candidate sites as a whole.

Results. Out of the first 200 x-sites in our survey design, one was on Federal and four on State land; another five sites were on land owned by local government entities; thus 5% of sites were nominally on public land. Of these, we did receive permission to access 140/200 sites (70%). Unfortunately, inspection of these results reveals a possible bias in permissions; see figure at right. We performed reconnaissance on all sites, independent of the permissions process. There were disproportionately more denials/nonresponses for those sites that were determined from desk and field reconnaissance to be dry or likely dry during summer sampling (χ^2=7.84, df=1, p<0.001).

Reconnaissance & Permissions Results



Site status (WET or DRY) based on preliminary desk and field reconnaissance, versus rates of landowner permission (PERM), denial (DENY) and nonresponse (NR).
We gained access to sample at only 57% of sites anticipated to be dry, compared to 76% of those anticipated to have water.

Questions and Strategies. Could it be that Kansas landowners thought they were doing us a favor by "saving us a trip" to a site with no water? We are not sure, but we have now re-written our permission letter to state *explicitly* that we would like to visit even dry sites and request return of permission forms regardless of flow status. Ten of the sites deemed "wet" were later found to be non-sampleable, which led us to improve our reconnaissance process for 2007 sites. What do we know about the "wet" sites for which we did not gain access – are they equivalent to the "wet" sites that were sampled? *Post facto* investigation of easily obtained metadata about these sites (estimated flow, ecoregion, adjacent land use patterns, nearby regulated point sources and diversions, etc.) compared to sampled sites may yield clues that dictate whether field investigation is necessary. We may need to adjust our final site weights, based on findings (Lesser 2001).

Parameters monitored

An overview of field methods

Overview. The Stream Probabilistic program collects biology and chemistry data using field methods and indicators from its two established parent programs. This facilitates integration and comparison of data across programs (KDHE 2007).

Biology and Physical Habitat. We establish a 150-m sample reach around the x-site. Macroinvertebrates are collected using a timed equal-effort method. Using kick/sweep-net and hand-pick methods, two individuals sample all available habitats (*e.g.*, substrate, root masses, logs, cobble) for a total of one person hour, with a target number of 200 organisms. These are identified in the lab and evaluated with a set of indices that reflect diversity and pollution tolerance of the community. Freshwater mussels and phytoplankton are surveyed also, and a Rapid Habitat Assessment is completed (Barbour *et al.* 1999).

Chemistry. For each x-site, a chemistry "companion" site is established at the nearest up- or downstream bridge crossing, barring confluences or point sources. Over 90% of sites in Survey Design A have a suitable companion site within 1.5 channel miles. Samples are collected quarterly and analyzed for over 90 parameters including nutrients, metals, pesticides, and bacteria.

Interpreting Data from Pooled Environments

A challenge for assessment

Biology and chemistry sampling success. In 2006, biological sampling was attempted only once at each site – during summer low flow. 62% (31/50) of sites yielded successful samples from flowing water, 18% (9/50) yielded samples from pooled water, and 20% (10/50) were not sampled because the channel was dry. In 2006, chemistry sampling was slightly more successful than biological, in part because samples were collected year round. Only about 5% of attempted sampling events (6/134) were unsuccessful due to dry channel; 76% (102/134) resulted in samples from flowing water, and 19% (26/134) resulted in samples from pooled water. At least one companion chemistry sample was taken for every biological site. Macroinvertebrate samples from 2006 are still being processed and identified, and chemistry data have yet to undergo the QA/QC checks required after laboratory reporting.

Discussion and challenges. Pooled sites present a major challenge for 2007 and beyond. First, we will give attention to accurately understanding the chemistry of pooled reaches (Fritz *et al.* 2006). A system that maintains hyporheic flow through an apparently discontinuous channel may respond quite differently from one in which flow is entirely interrupted and the drying process dominates instream conditions (Boulton 2003, Lake 2003). Drying may effect changes in conductivity, nutrients, and toxins (*e.g.,* Ostrand & Wilde 2004) and complicate relationships between surface and ground water (Dahm *et al.* 2003); biological processes and products contribute to these changes (Stanley *et al.* 1997). Second, even in the absence of daily streamflow records (Poff & Ward 1989), we will need to identify and refine parameters that will allow us to characterize intermittent streams in Kansas, especially with respect to biota (see Fritz & Dodds 2005). Researchers working in different stream systems have found everything from minor (*e.g,.* Delucchi 1988), to moderate (*e.g.,* Fritz & Dodds 2002), to substantial (*e.g.,* Lake 2003) differences between macroinvertebrate communities of intermittent and perennial streams. By integrating chemistry and physical habitat data with our biological results, we will hope to place intermittent Kansas streams in more understandable framework. Third, we will reconcile our understanding of pooled systems with our state's established water quality criteria (K.A.R. 28-16-28b *et seq.*) and assessment methodologies (KDHE 2006A). Intermittent streams are complex systems, and we anticipate that it will require a multistep process to grasp the biotic, abiotic and temporal factors that affect their quality and ecological functioning. Ultimately, our findings will help define the role of intermittent streams in the assessment and reporting on the quality of waters in the state.

Acknowledgements & References

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