A Case Study on the Quality Management System for the U.S. Geological Survey's National Streamgaging Program

1. Background

The United States Geological Survey (USGS) was established on March 3, 1879 by the Congress of the United States. The newly formed bureau was placed within the U.S. Department of the Interior and charged with the "classification of the public lands, and examination of the geological structure, mineral resources, and products of the national domain." Water was considered a valued mineral resource, essential to the irrigated farming methods necessary for settlement of the vast arid lands of the America west. Wise development of these lands and irrigation works would depend on knowledge of the magnitude and seasonal and inter-annual viability of streamflow. In order to acquire such information, the USGS, under Director John Wesley Powell, initiated the National Streamgaging Program with the establishment of the first streamgaging station (streamgage) on the Rio Grande River near Embudo, New Mexico, in 1889. This station was used as a field site for developing systematic data collection methods and providing training to the first USGS hydrographers and engineers.

In 1894 the Hydrographic Division was established as a regular unit of the USGS and received the first Congressional appropriation specifically for streamgaging activities. The program expanded with establishment of streamgages on many rivers throughout the Nation. In 1912 the USGS began installing and operating the first automated streamgage in the U.S. using a system that combined floats, pulleys, and chart recorders to monitor and record the fluctuations in river stage over time.

In the early days of the USGS, funding for the National Streamgaging Program (NSP) was provide entirely by Congressional appropriations, though some states and universities programs provided "in-kind services" such as labor. In 1924 an important change was made when Congress established the Cooperative Water Program (CWP) as a jointly-funded collaboration between the USGS and State and local agencies and Native American tribes. This program was enacted as a means for leveraging available Federal funds for use in establishing additional streamgages in cooperation with State and local agencies and tribal entities. CWP produced the additional benefit of creating professional ties between representatives of water resource agencies at all levels of government and a corresponding understanding of data needs at the local, regional, and national levels.

Surface-water monitoring and data analyses continue to be a significant part of the USGS overall mission of appraising the Nation's water resources. Surface-water information, including both stage and streamflow is used at the Federal, State, tribal, and local levels for resources planning and management. Specific Federal interests in the USGS streamgaging network are detailed in a report to Congress titled “Design of a National Streamflow Information Program” (http://pubs.usgs.gov/of/2004/1263/). This report identifies five Federal objectives to be addressed by the National Streamflow Information Program or NSIP. These objectives include 1) Compacts and decrees related to the transfer of international and interstate waters, 2) Water budgets, 3) Flood forecasting, 4) Water quality, and 5) Long-term trends. Furthermore, the report establishes the following key attributes of NSIP:

- Information is shared freely
- Information is readily accessible for current use;
- Information is centrally archived for future use;
- Information is quality-assured; and
- Information is viewed as neutral, objective, and of high quality by all parties.

Today the USGS operates more than 8,100 streamgages distributed throughout the U.S. (figure 1). A few of these stations are operated exclusively for producing stage records needed for flood forecasting and mapping while the majority are operated for producing both stage, streamflow, and in some cases, velocity records. Nearly all of these stations are instrumented with telemetry devices for the relay of hydrologic data in near real time. Both real-time and historic data and information resulting from the NSP are maintained and disseminated on the National Water Information System (NWIS) database at http://waterdata.usgs.gov/nwis. All of the stations are operated currently to the same standards, but the growth in demand for streamflow data, the rapid advancement in new instruments, and the democratization of computational resources and data dissemination tools have facilitated the entry of numerous independent private and academic entities who now provide local data of vastly differing quality and reliability.

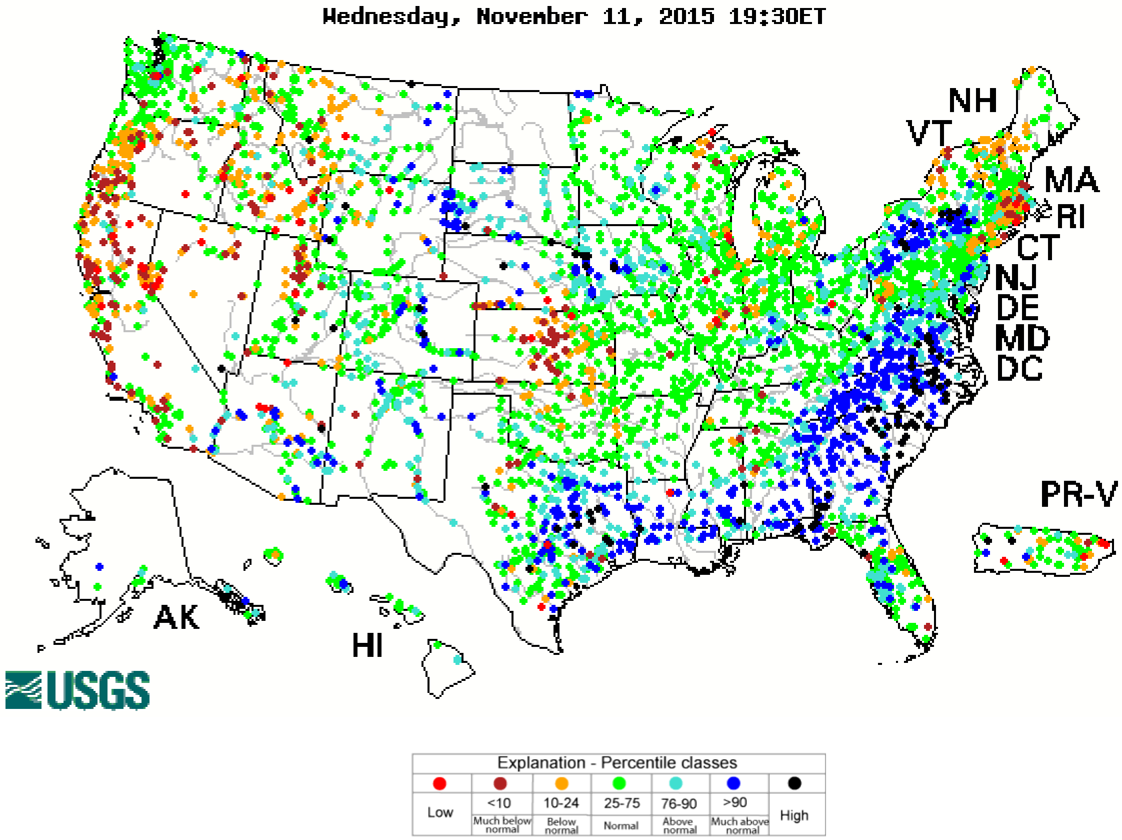

Figure 1. – Map showing the location of USGS streamgages and reflecting current streamflow magnitude relative to the long-term average.

Field operations of the NSP are carried out by personnel in 39 Water Science Centers (WSCs) throughout the U.S. and its territories and falls within the technical oversight of the Office of Surface Water (OSW). OSW is under the Water Mission Area (WMA), one of seven Mission Areas in the current USGS organizational structure. The WMA Office of Water Information (OWI) provides the computational software and enterprise level database and data dissemination tools that must be used by the WSCs. In 2014, the USGS WMA establish the Water Science Field Support Team (WSFT) to supplement OSW and provide additional, regionally focused technical support, assistance, and mentoring to WSCs.

2. The History of Quality Management (QM) within the USGS National Streamgaging Program

Providing high-quality and reliable hydrologic data has been the hallmark of the USGS NSP since its inception. The establishment of instrument testing and development facilities, nationally consistent training, publication of hundreds of technical reports and manuals, policy technical memoranda, and the implementation of a rigorous review process attest to the importance the USGS has placed on the quality of its surface-water data and information.

The first USGS streamgage at Embudo, New Mexico, was established as a field laboratory to develop standard methods that would result in the highest quality data possible, a need recognized early on within the bureau. The following quote is from an early Water Supply Paper (Corbett, 1943) that acknowledged the role of the Embudo station as a test and training facility.

"At that time, there were no systematic records of the flow of the streams and little knowledge of the methods that would best serve in obtaining such records; and no adequate instruments, apparatus, or equipment for collecting records of stage and discharge of streams were available. As a first and essential step in the investigation, Maj. J. W. Powell, Director of the Geological Survey, established in December 1888, a camp at Embudo, N. Mex., on the Rio Grande, where instruments and methods were studied and young men were instructed in the undeveloped art of stream gaging. With the establishment of the Embudo camp, the Geological Survey began systematic work in collecting records of stream flow and in studying the problems related to the utilization of water for irrigation and other purposes, and this work has continued uninterrupted to the present time."

Other facilities established for the development and evaluation of hydrologic instrumentation and hydraulic research include the Equipment Development Laboratory, Instrument Development Laboratory, OSW Hydraulic Laboratory, and the Hydrologic Instrumentation Facility (HIF). The HIF continues operating today with one of its primary roles being the testing of instruments against both manufacturer's and USGS specifications. The results of these tests are provided as internal, and increasingly, external reports to inform decisions on the acquisition of instrumentation with the objective of ensuring that the data collected by the NSP are of high quality and appropriate accuracy, precision, and resolution.

Continuing training for technical personnel is another area that has enabled the USGS to establish, maintain, and improve the quality of its surface-water data and information program. In the early years, training was provided through annual meetings and conferences of USGS hydrographers and U.S Bureau of Reclamation hydraulic engineers that were convened to facilitate and share innovations in the evolving field of hydrography and irrigation engineering. Regular correspondence through internal newsletters and notes and published water-supply papers dating to 1906, and on-the-job training underpinned USGS standardization and systemization of the work.

In the 1950s formal training began with a series of courses on hydraulic principles. In 1967 the National Training Center was established at the Federal Center in Denver, Colorado and continues to operate today under the USGS Office of Employee Development (OED) offering numerous classes on both field and office methods for the collection and production of surface-water data and records. Other technical surface-water training is offered by the OSW including a comprehensive series on the use of hydroacoustic Doppler technology for surface-water data collection. Additional training is provided by the WSFT. The training is coordinated by a WMA science and technician employee development team comprising representatives from OSW, WSFT, the WSCs, and the OED.

Since the inception of the USGS, technical reports and manuals have been published with the objective of establishing consistent standards for the collection of surface-water data. Report series such as “Techniques and Methods” (previously known as “Techniques for Water Resources Investigations” or TWRIs) and Water Supply Papers have provided engineers, scientists, and technicians at the USGS and other organizations with standard methods used in the field and office that when applied will ensure the data and information produced are of consistent and high quality. The following are just a few examples of reports that have been published over the years for the purpose of establishing, maintaining, and improving the quality of surface-water data collected by the USGS.

- Stream-Gaging Procedure, A Manual Describing Methods and Practices of the Geological Survey
  U.S. Geological Survey Water Supply Paper 888, 1943
  Don M. Corbett and others

- General Procedure for Gaging Streams
  USGS, Techniques for Water-Resources Investigations, Book 3, Chapter A6, 1968
  R.W. Carter and Jacob Davidian

- Measurement and Computation of Streamflow, Volumes 1 and 2
  U.S. Geological Survey Water Supply Paper 2175, 1982
  S.E. Rantz and others

- Stage Measurement at Gaging Stations
  U.S. Geological Survey Techniques and Methods book 3, chap. A7, 2010
  Sauer, V.B., and Turnipseed, D.P.

- Discharge Measurements at Gaging Stations
  U.S. Geological Survey Techniques and Methods book 3, chap. A8, 2010
  Turnipseed, D.P., and Sauer, V.B.

- Measuring Discharge with Acoustic Doppler Current Profilers from a Moving Boat
  U.S. Geological Survey Techniques and Methods, 3-A22, 2013
  Mueller, Wagner, Rehmel, Oberg, and Rainville

The following two excerpts are taken from the report on Stream-Gaging Procedure by Corbett, (1943) and provide a glimpse into the thinking at that time on the importance of establishing, maintaining, and improving the quality of the USGS NSP.

“The report has been prepared primarily for use in the training of young engineers for work in the Geological Survey. During 1938, 1939, and 1940 the number of new engineers added to the organization averaged 85 a year. The work of training these young men represents an undertaking that warrants the furnishing of the best possible facilities. ***The report will serve also to systematize, stabilize, and improve the work of streamgaging as a whole****. In a far- flung field organization it is not easy to obtain consistency in methods and results among many groups*

that perform their work without frequent contacts with each other. The report will be useful also in connection with the training of students in the engineering colleges an activity in which the Geological Survey is much interested because it must recruit its personnel from such students. It will also serve as an aid to practicing engineers who may be called upon to measure and record the flow of streams, as it contains much new and valuable information not to be found elsewhere in engineering literature. The information given relates to both the science of the flow of water in open channels and to the art of measuring and recording river discharge. ***Because the technique followed is perhaps as important as the instruments and equipment utilized, much attention is given to the details of the field procedures that have been found to yield the best records of river flow."***

"In an activity that is current, it must be understood that there will be continuing improvements*, and even as this report goes to press it is probably not strictly up to date, because of changes made in instruments or procedures since the latest revisions were made in the manuscript. It can be said, however, that the methods and practices described herein represented, in general, the best used by the Geological Survey at the time the report was prepared."*

The flagship component of the USGS approach to QM has been the technical review process overseen by the OSW in collaboration with the WSFT. Every three years each WSC and their associated field offices which have primary responsibility for the collection and production of streamflow data and records, are visited by a team of technical personnel coming from various other WSCs, WSFT, and OSW offices within the USGS. The mixed composition of practicing field hydrographers from peer offices across the Nation and technical experts with regional and National prospectives within the review team yields a powerfully authentic and motivating voice for the pursuit of quality, aids committed adoption of both standard and innovative streamgaging practices, facilitates personnel networking, and reinforces a National unity of purpose among all who participate in the process –both those whose hydrography work is under review and those who perform the review.

The team visits a select number of field installations, inspects field equipment, reviews office procedures, and reviews the database looking for ways to suggest improvements to the overall process. The final result of the review is a summary report to the Director of the WSC with a mandate that all major findings and recommendations be addressed. Progress towards implementation of the major recommendations is tracked by the WSFTs with occasional follow-up visits and reports.

3. QM Architecture, Implementation, and Supporting Documentation and Training

Quality management (QM) within the USGS is comprised of three primary components, which combined, form the Quality Management System or QMS. These components include the design or architecture of approaches used to ensure quality products, details of how the design is implemented within the NSP, and supporting documents and training that provide USGS policy and describe acceptable methods in the form of memoranda, reports, manuals, and training courses.

3.1. Organizational roles, strategy, and policy

Since 2012, the USGS is organized according to seven topical "Mission Areas", namely (1) Climate and Land Use Change, (2) Core Science Systems, (3) Ecosystems, (4) Energy and Minerals, (5) Environmental Health, (6) Natural Hazards, and (7) Water. The Water Mission Area has programmatic and operational responsibility for the NSIP. The Natural Hazards Mission Area and the Ecosystems Mission Area also have a vested interest in the NSP due to the support it provides both USGS and other agencies on issues related to flood hazards and ecosystems.

The Groundwater and Streamflow Information Program (GWSIP) provides the primary funding resources and thematic focus for NSP including the five NSP objectives plus development of innovative instrumentation and data applications such as flood-inundation mapping and extensive flood-response and documentation activities. Technical oversight for the NSP is vested with the OSW. Operational implementation is performed by the WSCs that are distributed throughout the Nation corresponding roughly to the States. USGS Streamgaging personnel are further distributed into Field Offices (FO).

One of OSW's primary roles is to establish policy, provide technical guidance, and ensure compliance with data standards, field methods, instrument performance (accuracy, precision, and resolution), records computational practices, and data management. Policy and technical guidance is passed down to the WSCs and FOs through their respective Regional Offices by means of technical memoranda. Since quality management of the NSP falls under the purview of OSW, QMS policy and guidance are commonly conveyed in this manner as well. Recent memoranda are archived electronically at http://water.usgs.gov/osw/pubs/techmemos.html. WSFT surface-water specialists provide additional technical support, consultation, and mentoring.

Reports and manuals are also used to convey OSW policy and technical guidance on topics related to the NSP, particularly when the breadth and complexity of the subject requires a lengthier format. The release of technical reports, manuals, or guidance documents, whether formally published or not, are announced to the WSCs and FOs by means of technical memoranda from OSW. This top-down structure provides consistency throughout the NSP, ensuring that all personnel are provided and have ready access to the most current information on accepted field methods, instrumentation, records computational procedures, and data management. This approach works well to ensure surface-water data provided by the USGS to end users are of high, quantifiable, and consistent quality.

The WSC's role in establishing and maintaining quality in the NSP is to ensure that technical staff are current on OSW policy and that these policies are being implemented. This is typically overseen at the WSC level by the Surface-Water (SW) Specialist who reports directly to the WSC Director. The WSC is also responsible for providing access to training for its technical staff to ensure that they not only are aware of accepted field and office methods but are capable of carrying them out. The WSC Director relies heavily on the SW Specialist to make recommendations on training needs and in some cases, to organize and conduct relevant training at the WSC and FO level. For example, given the dynamic improvements being regularly made in the area of hydroacoustic Doppler technology for hydrologic data collection, the need for frequent training is critical, not only for new, but also for experienced technical staff. To address this need in a cost-effective and timely manner many WSCs provide on-site training at FO locations on an annual basis. This allows for all staff to receive the training necessary to keep current on changes in technology while minimizing cost to the WSC and commitment of staff time away from their regular duties. This training is often planned and conducted by the WSC SW Specialist with assistance from other experienced staff within and from outside the WSC.

The WSC Director has the ultimate responsibility for ensuring the quality of data and informational products that are disseminated by the offices under his or her purview. The Director relies heavily on the results of the OSW Triennial Review summary report (described in detail in Section 3.2.3) as a guide for areas within the streamgaging program that need further attention and improvement. The Director is required to provide a written response to his or her supervisor within 90 days of receiving the summary report detailing how recommendations made in the report have been or will be addressed. During the following Triennial review the previous review's summary report recommendations are revisited by the review team and any areas that have not been adequately addressed will be highlighted.

3.2. QMS Implementation

Though managed from the top down, as described in the previous section, quality management (QM) practices in the USGS NSP are collaborative and shared (figure 2) and are more clearly described as they are implemented, from the bottom up, beginning at the WSC and FO levels. The bases for QM practices at this level are documented in the WSC Surface Water Quality Assurance (QA) Plan. OSW provides a template (http://water.usgs.gov/osw/furnished_records/) for the plan to ensure consistency throughout the organization and requires that each WSC maintain an up-to-date plan specific to their unique hydrologic environments. The QA Plan is a comprehensive document that establishes QM procedures for all aspect of the streamgaging program including establishment and operation of individual monitoring stations, field data collection methods, records computation, data management, and oversight.

3.2.1. Field Office

In any surface-water monitoring network the fundamental building block is the monitoring station where the raw, unadjusted data are collected. In the USGS this work is typically conducted at the Field Office level. Quality in hydrologic data and information cannot be a value-added product but rather must be built into each monitoring station both during establishment and throughout its operation and maintenance. Ensuring quality at the station level is essential to developing a streamgaging program that produces timely, high quality data and informational products.

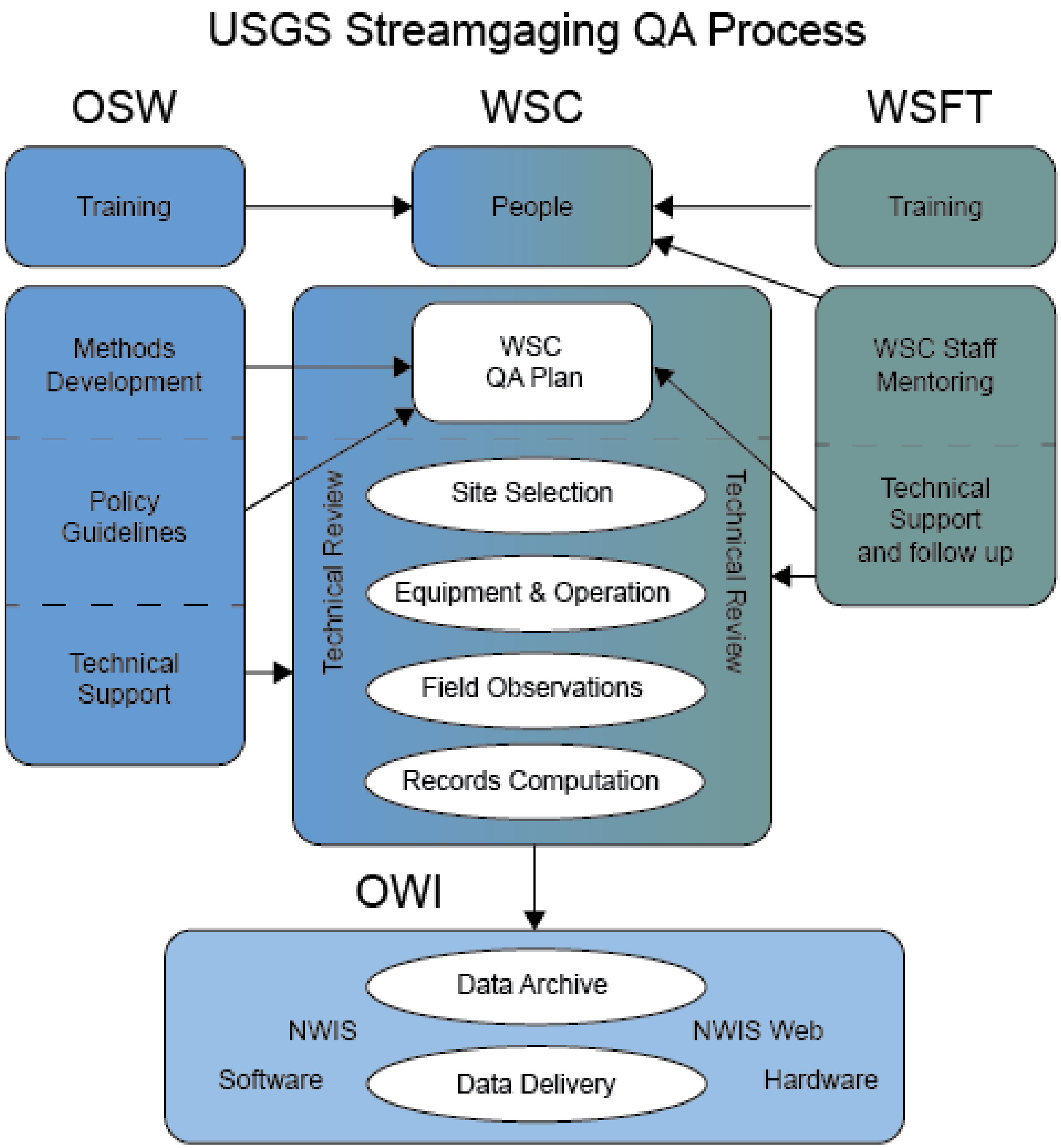

Figure 2 --USGS quality monitoring system for streamflow data. [WSC -Water Science Center; OSW -Office of Surface Water; WSFT -Water Science Field Team; OWI -Office of Water Information; NWIS -National Water Information System.]

Establishment of monitoring stations

The establishment of a new monitoring station is driven by the need for data. The purposes for which these data and resulting information must be clearly understood and defined before any field work proceeds. Considerations include the need for proximity to specific planned or established water infrastructure, river forecasting location, ecosystem habitat of concern, pollution source, or scientific study for which representative data is sought, and the type, periodicity, range, and duration of the data-collection effort. At times, stations are established primarily to provide regional sampling and understanding of streamflow characteristics, thus new locations might be established to fill gaps in network coverage of hydrologic, geologic, topographic, climate, or developmental basin characteristics sometimes identified through discussion with local State and municipal water managers and sometimes by the GWSIP and OSW. Taking time to document the objectives to be achieved in the establishment of a new streamgaging station will avoid costly mistakes and ensure that objectives can be met.

Once objectives are clear the next step is to locate an appropriate site for the monitoring station. Many factors come into play when making this decision including channel and hydraulic characteristics, seasonal conditions, access, and security. Indeed, the sensitivity and stability of the control is a key factor influencing the quality and uncertainty of the resulting streamflow information.

After a site has been located the next step in the establishment of a station is to identify the type of instrumentation that will be required to obtain data of sufficient quality to achieve the objectives of the station and to install the instruments and associated infrastructure in such a manner that data will be collected accurately and reliably.

The establishment of “gage datum” at a newly established site is the final step and of critical importance. The datum is the elevation that all subsequent water levels will be referenced to. In the past an arbitrary elevation was established for this purpose due to the difficulty of surveying in an elevation based on mean sea level or other national or regional coordinate system. With the availability of GPS it is now simple and inexpensive to establish an elevation based on a real-world coordinate system and thus this approach has become increasingly common.

Each of the steps necessary in the establishment of a new streamgage requires careful consideration to assure that the final data and informational products are of appropriate, consistent, and quantifiable quality. For the purposes of this paper the term “high-quality data” will be used to describe these characteristics. Though the USGS NSP operates thousands of streamgages spread across the landscape in widely diverse hydrologic conditions and settings it maintains the required data standards through dissemination and adherence to policy and methods by means of memos, reports, manuals, training, and on-site reviews. Useful sources of information that provide details and guidance on site selection, instrumentation options, installation practices, and establishment of datum can be found in Rantz (1982), Kennedy (1990), Mueller (2009), Kenney (2010), and Sauer (2010).

Field data collection at monitoring stations

Following establishment of the monitoring station effective QM practices play a critical role in the ongoing collection of high quality data. These practices apply to the operation and maintenance of the monitoring station as well as field data collection methods. For example, it is current USGS policy that a discharge measurement must be fully computed in the field and compared to the current stage-discharge relation, or rating, before the hydrographer departs the station. If the discharge plots more than 5 percent off the rating the hydrographer must evaluate the physical conditions at the site, particularly the hydraulic control, and identify and note a reasonable explanation for the discrepancy. This might be an observation of filling or scour of sediment in the hydraulic control since the last measurement or the growth of aquatic vegetation leading to a change in the physical properties of the control. If no reasonable explanation can be identified the hydrographer is required to make a check measurement of discharge. Other examples of USGS QM policies affecting field data collection include 1) the allowable percent of unmeasured zones near the edges, surface, and bottom of a channel when making a measurement with an acoustic Doppler current profiler; 2) the correct procedure for computing the stage assigned to a discharge measurement when the flow rate is changing; or 3) how often are levels required to be run at a station to verify datum accuracy. There are literally hundreds of these QM policies that USGS field personnel are required to be aware of and implement to ensure that high quality data are collected.

Policy memoranda from OSW pertaining to the collection of surface-water data can be found at http://water.usgs.gov/admin/memo/SW/. An example of a policy statement that addresses QM issues is the Office of Surface Water Memorandum no. 93.07, Policy Statement on Stage Accuracy. This policy establishes accuracy goals for the collection of surface-water level (stage) and describes the analytical approach used to quantify these goals. An excerpt from the policy memorandum that is of a subjective nature states: *"Because the uses to which stage data may be put cannot be predicted, it is OSW policy that surface water stage records at stream sites be collected using instruments and procedures that provide sufficient accuracy to support computation of discharge from a stage-discharge relation, unless higher accuracy is required."* The same memorandum also provides a more objective description of the accuracy goals as follows: *"An acceptable balance between stage-measurement accuracy and other components of discharge-record accuracy can be achieved by using instruments capable of sensing and recording stage with an accuracy of either 0.01 ft or 0.2 percent of the effective stage being measured, whichever is less restrictive."*

OSW policy memos are typically only a page or two in length and used to advise personnel of policy related to the establishment or revision of standards, or to alert them to the publication of a report or manual that more thoroughly addresses technical topics. Studies and reports are commissioned by OSW to provide personnel with technical information on field and office procedures and methods that require too much detail to be contained in a memorandum. An early report containing general guidance and information on USGS accepted streamgaging practices can be found in "Stream-gaging procedure; a manual describing methods and practices of the Geological Survey" (Corbett, 1943). As data requirements change over time and improved instrumentation becomes available, updates to methods for collecting data are required. Consequently, new reports describing current methods in light of changing objectives and technologies are regularly published. Examples include: “Measurement and computation of streamflow, volumes 1&2” (Rantz, 1982) and “Discharge measurements at gaging stations” (Turnipseed and Sauer, 2010).

Since the early 1990’s the development of acoustic Doppler instruments has dramatically changed field methodology in the area of surface-water data collection. The technology continues to change rapidly with new instruments and capabilities becoming available every year. To keep up there has been an associated need for policy memoranda as well as technical reports and manuals to ensure that QM practices are addressed as new technology is incorporated into the NSP. Recent reports covering topics associated with acoustic Doppler instruments include: “Quality assurance plan for discharge measurements using acoustic Doppler current profilers” (Oberg, Morlock, and Caldwell, 2005) and “Measuring discharge with acoustic Doppler current profilers from a moving boat” (Mueller and others, 2013). QM practices for ADCPs are specified in these reports with topics covering 1) required training prior to ADCP use, 2) software and instrument diagnostic tests prior to data collection, 3) field procedures including site selection, instrument configuration, moving-bed tests, and discharge measurement procedures, and finally, 4) measurement review and archival.

Many other topics covering the operation and maintenance of field stations and field methods for surface-water data collection are contained within various USGS reports and manuals, most of which can be accessed on-line at no charge at the USGS Publications Warehouse (http://pubs.er.usgs.gov/) or at the USGS Surface Water Information Page maintained by OSW (http://water.usgs.gov/osw/). A selection of relevant reports and manuals are also listed with links for web access in the last section of this report.

Computation of Records

For many years the computation of streamflow records at USGS offices was done using practices that resulted in the data and informational products being released in the form of a published “Annual Data Report” approximately six months after the end of the preceding water year. The advantage of this approach was that it allowed the hydrographer the luxury of having an entire year’s worth of stage and discharge data to evaluate prior to finalizing ratings, shifts, datum corrections, and the computed records. The main disadvantage in the approach was the delay in access to finalized data and records by the end user.

In the 1970’s satellite technology became available allowing a few stations to transmit data in near real-time directly to USGS offices by means of geostationary communication satellites. Over the intervening years advances in technology have resulted in nearly all of the USGS stations being instrumented with telemetry devices so that today most of the NSP’s data can be accessed in near real time. This has led to some amazingly useful products such as WaterWatch (http://waterwatch.usgs.gov/) where the status of surface-water hydrology throughout the entire nation or any specific region of interest can be accessed and evaluated in a matter of minutes or even seconds. Smart phone applications are also available which allow end users to access real-time streamflow data almost anywhere and at any time.

One result of these impressive advancements in data access has been to put increased demands on all facets of the USGS NSP, from field operations to website administration, thus requiring that data and information are reliably available whenever and wherever needed. To address these changes the USGS has recently implemented something called the “Continuous Records Process” or CRP which places each streamgage into one of three categories depending upon the feasibility of producing and finalizing records in near real-time. OSW policy states that Category 1 stations, which is the standard category, are required to have their records computed and finalized within 150 days of collection. Category 2 stations are identified as stations needing additional data to accurately compute the records and should be finalized within 240 days. Category 3 stations are special cases where continuous records processing does not apply. For details of this policy see the applicable USGS memo at: http://water.usgs.gov/admin/memo/policy/wrdpolicy10.02.html). Furthermore, measurement data, and rating and shift updates are required to be entered into the National Water Information System (NWIS) database within two days of collection. Achieving this faster turnaround while maintaining QM standards has required changes in field and office procedures. For example, hydrographers now carry computers, tablets, or other devices into the field that are capable of running specialized hydrologic software applications. These applications are used to maintain all documents relevant to individual streamgaging stations, capture field notes, download and plot data, and analyze ratings and shifts after input of the latest discharge measurement. For example, once a discharge measurement is collected at a station the hydrographer compares it to the current rating, and required rating, shift, and datum updates are then uploaded to the database in less than 48 hours ensuring the most current data, records, and information to be immediately disseminated to the end users.

Following the hydrographer’s return from the field all field notes, data, and computations are electronically transmitted to and reviewed by an independent checker to ensure that they are complete, thorough, and accurate. They are then transmitted to a senior hydrographer for a final technical review in which all shifts, rating changes, and datum adjustments are evaluated to ensure they have a good hydraulic and hydrologic basis. Following this review the records are either sent back to the responsible hydrographer for revisions or are approved. Once approved, they are set to “Approved” and “Locked” in the NWIS database so that no further changes can be made. Only under unusual circumstances will locked records be unlocked for further revisions.

3.2.2. Water Science Center

The WSC provides oversight and guidance to FO personnel on issues related to QM of the NSP primarily through the Data Chief and the Surface-Water (SW) Specialist. The Data Chief oversees the WSC Data Section and has direct supervisory authority over the Field Office Chiefs while the SW Specialist plays a technical advisory role to the Data Chief and

FOs but without supervisory authority. Both the Data Chief and SW Specialist report directly to the WSC Director.

The Data Chief is responsible to ensure that FO personnel have the necessary training and equipment to carry out their jobs according to standards set by OSW policy and dictated by the SW QA Plan. He or she is also responsible for implementing the NSP's internal audits that are established in the QA Plan. Internal audits include various scripts that interrogate the data base looking for data gaps, erroneous data, lack of recent measurements, or equipment diagnostics such as low battery voltage. Some of these internal audits are run on a daily basis with results sent by email directly to the responsible hydrographer and supervisor for their attention and response. The SW Review script (URL: http://water.usgs.gov/osw/furnished_records/) is run annually to aid in the evaluation of the overall status of the WSC's Streamgaging Program and also during the OSW triennial review.

The SW Specialist monitors policy memos and methods reports sent from OSW that pertain to the NSP and ensures that all affected personnel are aware of and understand these policies and methods. The SW Specialist provides recommendations to the Data Chief and WSC Director when areas are identified in the program in need of improvement. The SW Specialist often supports the Data Section and thus the NSP by both conducting and coordinating in-house training on field and office methods and practices related to SW data collection and analyses.

Two other QM functions performed by the WSC are related to furnished records from outside agencies and international stations on the U.S. and Canadian border. Some WSCs have collaborative agreements with other agencies that operate their own streamgaging stations. Often these agencies request that the USGS include data, streamflow records, and information in the National Water Information System (NWIS) database. Archival and management of data in NWIS is a significant benefit to the requesting agency while the USGS and end users of these data also benefit by having access to additional streamflow records in a single location and format. The USGS is usually willing to take on this added responsibility but requires an annual review of the data provider's program including on-site station visits to ensure adequacy of facilities and instrumentation and to verify that field methods meet USGS standards. A thorough review of records computations, similar to the internal reviews conducted in each FO, is also required before data are published in NWIS.

Several international streamgaging stations are operated on rivers crossing between the U.S. and Canada which have treaties that dictate flow volumes and timing. These stations are operated under oversight by the International Joint Commission (IJC), an independent binational organization established by the United States and Canada under the Boundary Waters Treaty of 1909. Streamgages in this program are collaboratively operated by both USGS and Water Survey Canada (WSC) personnel located in offices with jurisdiction over the respective transboundary streams. The records are reviewed and approved annually by each agency to verify treaty compliance and ensure that streamflow data and records of high quality are being produced.

3.2.3. Water Science Field Team

The WSFT was established by the WMA in 2014 to remedy the loss of regional focus and support following a USGS-wide reorganization through which that support was lost. Today, four regional specialists are assigned support and mentoring responsibilities for specific water science centers. The specialists work closely with OSW to develop OW policies and practices and explain them to the WSCs, while simultaneously advocating for WSC concerns and needs. The resulting three-way partnerships ensures better communications, consistent application, and enterprise-wide commitment to the standards and practices needed to ensure that USGS streamflow data collected in one part of the country are as relevant to National uses, such as climate change and water management, as data collected in any other part.

3.2.4. Office of Surface Water

As mentioned earlier, final oversight for quality management of the USGS NSP is the responsibility of OSW. This oversight is conducted in three primary ways, technical support, training, and review.

Technical Support and Guidance

OSW provides technical support for the USGS NSP through the operation of test facilities such as the Hydrologic Instrumentation Facility (HIF), technical committees, and through the publication of technical reports and manuals.

The HIF tests, evaluates, repairs, calibrates, and develops hydrologic equipment and instruments. Instruments are tested against both manufacturer and USGS specifications. The results of these tests are provided as internal reports to USGS Water Science Centers to inform decisions on the acquisition of instrumentation with the objective of ensuring that data of high quality and appropriate accuracy, precision, and resolution are being collected. HIF Hydraulic Laboratory facilities include a towing tank, jet tank, pipe-flow facility, and tilting flume. All of the facilities are verified and calibrated by independent metrology labs with references that are traceable back to the National Institute of Standards and Technology (NIST). NIST is the agency of the United States Federal Government, Department of Commerce responsible for developing, maintaining and disseminating national metrology standards (http://www.nist.gov/index.html).

In addition the HIF provides training and technical support on equipment that it stocks in its sales and rental program. Additional information about services and support offered by the HIF can be found at their website: http://water.usgs.gov/hif/.

OSW sponsors several committees which support the surface-water hydrology community. Two of these committees provide significant support for the NSP. First is the USGS Global Navigation Satellite System Committee which maintains the following website: (http://water.usgs.gov/osw/gps/index.html. This site is designed to provide users with technical information on various types of GPS equipment and guidance on best practices, training opportunities, websites, and publications focused on the use of GPS equipment in the collection of surface-water data. The useful information provided at this site is of particular interest to field hydrographers who need to establish and maintain accurate datum at streamgaging stations.

The second committee sponsored by OSW which directly supports the NSP is the Hydroacoustics Work Group or HaWG. HaWG provides guidance to OSW on topics related to the development of hydroacoustics instrumentation and facilitates communication between OSW and the hydroacoustics community both within and outside the USGS. The rate at which hydroacoustic technology is changing and improving has placed great demands on the NSP as it attempts to maintain the quality of its data and information while integrating this new technology. The HaWG website (https://hydroacoustics.usgs.gov/) provides users with an outstanding resource of information on instrument and software evaluations, field methods, reports, websites, technical forums, and training opportunities that are aimed to maintain and improve the quality of surface-water data and informational products both from the USGS and numerous other agencies and organizations worldwide.

Technical reports and manuals have been one of the primary tools for maintaining quality standards in the USGS NSP throughout its existence. Early reports such as Corbett (1943), Smoot and Novak (1968), and Buchanan and Somers (1969) provided details covering topics including the calibration and maintenance of flow meters, field methods for making discharge measurements, and general practices for the operation of streamgaging stations. As technologies and methods evolved the demand for updated reports and manuals grew as well. This need was met through reports such as Rantz (1982) and technical series such as Techniques of Water-Resources Investigations and more recently the USGS Techniques and Methods series. Many other reports have been published that cover a wide range of topics including site selection, instrument use, gage datum, rating and shift analysis, records computation, and data management. A list of selected reports and manuals and websites where they can be accessed are provided in the References Section of this Case Study.

Also worth noting, given its relevance to this study, is an unpublished report that was written in 2010 by a team comprised of USGS technical personnel and representatives from four hydrologic instrument manufacturing companies. The report titled “USGS Value Engineering - Surface Water Study Report to WRD Senior Staff” provided a detailed review of workflow processes within two USGS FOs and made recommendations for areas of improvement. The report led to the integration of several software applications designed to improve the efficiency of processes and document management both in the field and office.

Training

One of the most important avenues of QM within the USGS NSP is the ongoing training of personnel to both develop and maintain skills in field, computational, and data management methods and practices. As mentioned, training is regularly provided at the WSC level but significant training opportunities are also provided by OSW through the HIF, HaWG, and the National Training Center. In addition there are numerous courses offered on-line in the form of interactive and webinar training as well as podcasts. OSW has developed recommended training timelines for all technical personnel and provides support for the courses in whatever format they are offered (URL: http://pubs.usgs.gov/fs/2007/3099/).

Technical Reviews

Of all support provided by OSW, the conduct of the triennial Surface-Water Review for each WSC is probably the most effective for maintaining the quality of the NSP. Every three years, on a rotational basis, each WSC hosts a team of reviewers assembled by OSW, who conduct a thorough evaluation of the WSC's Surface-Water Program with particular focus on the NSP. The team is typically comprised of a lead person from OSW, the Regional SW Specialist, and several other members selected from WSCs around the U.S. The team members are selected with attention to the unique hydrologic issues and conditions common to the WSC being reviewed. For example, a team traveling to a WSC in Florida where stream slopes are low and tidal-affected streams are common would likely include a member with technical expertise in the use of acoustic Doppler velocity meters for monitoring unsteady, bi-directional flows. Each review team includes personnel experienced in the operation and maintenance of streamgages who are assigned the task of visiting the FOs and a selection of the streamgages they operate. Depending upon the needs of the WSC, other personnel with expertise in field data collection, records computation, and data management will make up the remainder the team's membership. By creating a team that is able to address the particular needs of the WSC a thorough review can be conducted and of equal importance, the cross-pollination of ideas and solutions through verbal exchanges during the review are of benefit to both the WSC and OSW review team personnel.

On-site members of the review team choose and inspect a select number of streamgages to verify the adequacy and maintenance of the instrumentation, equipment, and facilities. They also inspect flow meters, field vehicles, and warehouse facilities. Several streamflow records are randomly chosen by the team and thoroughly reviewed along with the WSC SW QA Plan and Flood Plan. Velocity meters from each FO are also traded out with similar meters brought by the team as part of the HIF Current Meter Exchange Program. These meters are sent to the HIF for testing against established standards of accuracy and the results included in the final review summary report.

The SW Review Script is run by remote reviewers on the WSC's SW database and performs many diagnostic tests to identify such things as data gaps, outlier data, non-approved data, and status of the Peak Flow File. The results of this automated review are captured in a report that is referenced in the final Summary Report provided to the WSC management following the review.

At the end of each FO review the responsible team member sits down with the FO personnel to discuss issues of interest and technical topics and to provide an overview of the findings. At the end of the WSC review the team meets with WSC management including the Director, Data Chief, Investigations Chief, Surface-Water Specialist and other appropriate personnel and provides an oral report on their findings. A final Summary Report is produced by the team, using a standard template to provide consistency, and is transmitted through Regional Management to the WSC Director within eight weeks of the completion of the review. The objective of the Summary Report is to draw attention both to areas of excellence and where improvements are needed in the WSC streamgaging program. The WSC is required to respond in writing to the report within eight weeks of receipt of the Summary Report, specifically indicating how all major recommendations have been or will be addressed. This response is sent to OSW through Regional Management to assure accountability and follow up.

Recently, OSW has required the review teams to use structured spreadsheets with detailed questions and criteria that drive a systematic review of WSC NSP operations and result in quantifiable metrics that can be tracked from review to review. These spreadsheets have greatly improved the effectiveness of the review process and have resulted in improved data quality. Copies of the spreadsheets and other information concerning the USGS quality assurance process (and information concerning the procedures and requirements for submitting “furnished” streamflow records for possible incorporation into the USGS database are available at URL http://water.usgs.gov/osw/furnished_records/.

4. Challenges with Implementation of the QMS

The design and implementation of QMS in the USGS NSP has been an evolving process from the establishment of the first streamgage 127 years ago until the present time. Over this period the rate of change in QMS processes has been proportional to the understanding of hydrological processes, development of field and analytical procedures, and advancements in monitoring technology. During the past 30 years however, the rate has accelerated with every indication that it will continue with a resulting increase of demands on all facets of the program.

One of the biggest challenges has been to find the right balance between the quality and accuracy of data and information and the speed with which they are disseminated to users. Finding this balance is made more difficult because of differing demands of data users which are often at cross purposes with each other. For example, a large number of USGS hydrologic data customers are involved in resource management or facilities operations of one type or another. This would include agencies with flood forecast responsibilities, irrigation water supply managers, or hydroelectric powerplant operators. Anything less than access to near-real time data is generally unacceptable to these customers even if it means compromising some level of data quality. On the other end of the spectrum are planners and designers who are interested in long-term data sets for various types of statistical analyses where data accuracy and quality are of utmost importance. Balancing these competing needs with limited resources is made especially challenging when our data customers are often providing some or all of the funding required to operate certain stations in the network. Maintaining an appropriate level of quality, accuracy, and timeliness in our data and informational products while balancing the competing needs of all of our customers including the Federal interests continues to be a difficult challenge.

An equally difficult challenge relates to the cost associated with implementing a QMS. These costs are not easily quantified because the various aspects of QM are built into the fabric of every part of the NSP. Examples have been described in the previous sections of this report and include operation of testing facilities, publication of methods reports, training, and reviews of both operations and databases. These all play a role in the USGS QMS and all have an associated cost which comprises a significant part of the cost of running a streamgaging network. As resources become tight it is tempting for the entities that provide NSP funds to consider less expensive alternatives without having a clear understanding of what will be sacrificed in terms of quality, continuity, and long-term database management.

Maintaining the relevancy of the QMS is an ongoing issue that bears some attention. As stated, QM procedures are developed and implemented at a given point in time, often with careful consideration as to how they will enhance the quality and utility of the NSP's data and informational products. However, if these procedures are not reviewed from time to time to evaluate their continued relevancy the QMS can end up becoming a detriment to the program that diminishes rather than enhances its value.

A final challenge worth mentioning is related to continuity of the QMS given today's workforce mobility. This is especially evident at the WSC level where continuous changes in methods and instrumentation are occurring due to ever-changing technology. Often a single person at the WSC level, such as the SW Specialist, is assigned to monitor and disseminate new policies and methods coming from OSW and ensure that they are implemented quickly and correctly. This staffing arrangement, which directly affects the QM of the NSP, will be disrupted for a period of time when this person moves or retires. Strategies need to be considered and implemented in advance that will avoid this otherwise inevitable problem.

5. Lessons Learned while Implementing QMS

Newly established NHS organizations or those going through significant rebuilding are faced early on with the decision of whether to implement a formal QMS, and if so, at what level. The tendency is to put off establishing a formal process with the idea that it can be undertaken at a later date after the primary business of building monitoring stations, collecting data, and producing records is underway. The short-sighted rationale being that a QMS will distract from the important work of network startup and the costs of implementation will take away from available funds. While true that establishing a QMS is not without costs some important factors should be considered when weighing the alternatives.

- The cost and effort to implement a QMS will be less if started in the early stages of streamgaging program development.
- Establishing a QMS after a program is underway will often result in the need to rebuild infrastructure to higher standards and retrain personnel on QM operational practices.
- Data collected, disseminated, and archived without a QMS in place will be of uncertain and often lower quality.

- Costs of implementing a QMS and the associated improvement in data quality will result in accrued public benefits such as more accurate and timely flood warnings and better design of infrastructure such as dams, bridges, and water treatment plants.
- A good QMS instills confidence in the data by the end users. For example when inevitable controversies arise related to hydrologic analyses for resource planning and management, high-quality data produced by the streamgaging program with a QMS in place will provide a mutually agreeable basis for solutions.

It's also worth noting that not all elements of a QMS described in this Case Study need to be implemented at the outset of NHS establishment. Certainly station installation, data collection and analytical methods, and data management considerations should be essential elements, but there are many resources available through other established organizations such as WMO and USGS that can be utilized. Readily available resources such as training, reports, manuals, websites, and on-line forums can provide valuable QM tools for a new NHS at little or no cost.

6. Improvements and Efficiencies Gained since Establishment of QMS

A primary focus of QMS is discovering ways to continuously improve a process. Any national streamgaging program will include a complex group of processes that will benefit from establishing a QMS. Some examples of improvements and efficiencies gained in the USGS NSP as a direct result of its QMS are as follows:

- Having a central office such as OSW that provides policy and guidance on acceptable field and office procedures improves the overall quality of data and information through useful and timely reports and manuals and regular reviews. For example, the Techniques for Water Resources Investigations series of reports has provided technical personnel working in the widely distributed USGS NSP with a resource that improves both quality and efficiency by establishing and disseminating acceptable practices. Reports and training are updated as required by changing field practices and the availability of new instrumentation. The result of this focus on continuous improvement has been data and informational products of the highest possible quality.
- The testing of instruments and equipment and resulting evaluation reports provided by the HIF to WSCs are a valuable resource for the USGS NSP. These in-house reports provide useful and timely guidance for WSCs making purchasing decisions, which in turn helps them avoid costly mistakes on inferior or inappropriate products and ensures high-quality data are produced by the program.
- The recent addition of automated scripts such as GO2 and SW Review, which are designed to interrogate the database and summarize possible areas of concern or deficiency, have provided a valuable feedback tool for technical personnel in the NSP. These scripts, run on a daily, monthly, annual, or triennial basis, are used by field, office, IT, and managerial staff, and serve as a basis for continually improving the operation of and products provided by the program.

- The OSW triennial review of WSC operations and the database was established decades ago and is one of the most effective tools in the NSP's QMS for establishing and maintaining a high-quality program. The OSW Review employs technical experts from outside the WSC to provide a thorough and unbiased review of field, office, and database processes. In every instance the review's Summary Report provides beneficial recommendations to the WSC that facilitate the process of continual improvement.
- Another benefit afforded by the OSW Review process is the cross-pollination of ideas related to methods, equipment, and operation of the program. This exchange of ideas takes place during the week of the review as technical personnel from throughout the NSP meet with their counterparts at the WSC. New ideas and approaches are discussed and the good ones are naturally transferred to other offices around the country. Thus the OSW Review serves as both an incubator and transfer mechanism for new ideas and methods.
- The establishment of SW QA Plans at the WSCs based on a standard template from OSW has resulted in improved consistency of data across the USGS NSP. Each WSC is provided the standard template and is required to customize it to their particular situation. Every three years during the OSW Review the QA Plan is reviewed to ensure it is current. The establishment of common practices for data collection, records computation, and data management has resulted in a streamgaging program with consistent and high-quality products throughout a widely distributed network.

7. Contact and Access to Documentation

7.1. Other QMS within USGS

Though the focus of this document is the QMS implemented for the NSP the USGS also maintains an active QMS in other facets of its Surface-Water Program as well as all other water related disciplines including Groundwater, Water-quality, Sediment, Water use, laboratories, and IT. The Office of Groundwater (OGW) and the Office of Water Quality (OWQ) provide support similar to OSW for their respective disciplines. National QM processes are in place for the National Water Quality Laboratory (NWQL) and the National Water Information System (NWIS). WSCs also maintain QA Plans for their groundwater, water-quality, and sediment programs.

7.2. QMS Contacts in USGS Water Mission Area

Office of Surface Water
Name: James R. Kolva
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Office of Groundwater

Name: Linda Debrewer
Email: lmdebrew@usgs.gov

Office of Water-Quality
Name: Cherie Miller
Email: cvmiller@usgs.gov

7.3. Relevant QMS Documents and Websites

7.3.1. Reports

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OSW Publications
http://water.usgs.gov/osw/pubs.html

Techniques of Water Resources Investigations (TWRI)
http://water.usgs.gov/osw/pubs.html

USGS Publications Warehouse
http://pubs.er.usgs.gov/

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All OSW memoranda
http://water.usgs.gov/admin/memo/SW/

7.3.3. Training

HIF Training Courses
http://water.usgs.gov/hif/programs/training/

Hydroacoustics Training Courses
https://hydroacoustics.usgs.gov/training/index.shtml

Hydroacoustics Webinar Courses
https://hydroacoustics.usgs.gov/training/webinars.shtml

Hydroacoustics On-demand Courses
https://hydroacoustics.usgs.gov/training/webinars.shtml

Surface Water Techniques On-demand Courses
http://pubs.usgs.gov/fs/2007/3099/

7.3.4. Websites

Office of Surface Water
http://water.usgs.gov/osw/

Hydrologic Instrumentation Facility
http://water.usgs.gov/hif/

Hydroacoustics
https://hydroacoustics.usgs.gov/

Global Navigation Satellite Systems/GPS
(http://water.usgs.gov/osw/gps/index.html