Erosion and Sediment Transport Monitoring Programmes in River Basins (Proceedings of the Oslo Symposium, August 1992). IAHS Publ. no. 210, 1992.

Monitoring radionuclide and suspended-sediment transport in the Little Colorado River basin, Arizona and New Mexico, USA

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ABSTRACT From July 1988 through September 1991, radionuclide and suspended-sediment transport were monitored in ephemeral streams in the semiarid Little Colorado River basin of Arizona and New Mexico, USA, where in-stream gross-alpha plus gross-beta activities have exceeded Arizona's Maximum Allowable Limit through releases from natural weathering processes and from uranium-mining operations in the Church Rock Mining District, Grants Mineral Belt, New Mexico. Water samples were collected at a network of nine continuous-record streamgauges equipped with microprocessor-based satellite telemetry and automatic water-sampling systems, and six partial-record streamgauges equipped with passive water samplers. Analytical results from these samples were used to calculate transport of selected suspended and dissolved radionuclides in the uranium-238 and thorium-232 decay series.

INTRODUCTION

The U.S. Geological Survey (USGS) monitored the occurrence and movement of radionuclides and other trace elements in selected water resources in parts of the 70 000-km^2 Little Colorado River basin of Arizona and New Mexico, USA, from July 1988 through September 1991 (Fig. 1). Study objectives were to evaluate types, concentrations, transport rates, and recent origins of radionuclides and other trace elements in surface water and groundwater and to assess movement of these constituents between surface water and groundwater. This paper describes the methods used to monitor radionuclides and suspended sediment in streamflow.

History of Radionuclide Releases

Radionuclides in the uranium-238 and thorium-232 decay series, which occur in relative abundance in the Little Colorado River basin of Arizona and New Mexico, enter the hydrologic cycle through natural weathering processes. Additionally, uranium-mining operations in the Church Rock Mining District (CRMD) in New Mexico's Grants Mineral Belt upstream from Gallup, New Mexico (Fig. 1), resulted in the dispersion of these radionuclides and other potentially hazardous trace elements to the environment. A cumulative 22 years of mine dewatering between 1960 and 1986 from the CRMD released an estimated 560 t of uranium and 260 Ci of gross-alpha activity to the Puerco River, a tributary of the Little Colorado River (Van Metre & Gray, 1992). Additionally, failure of a uranium tailings pond in the CRMD on July 16, 1979, resulted in the single largest release of uranium tailings liquid in U.S. history. A total of 378 500 m^3 of pH 1.9 liquid and 1000 t of tailings containing an estimated 1.5 t of uranium and 46 Ci of gross-alpha activity were released to Pipeline Arroyo, a tributary of the Puerco River (Graf, 1990; Gray & Webb, 1991; Van Metre & Gray, 1992). Tailings liquid flowed about 130 km in the Puerco River before dissipating into the alluvium (Hussein Aldis, Ecology and Environment, Inc., 1979, written commun.). Gross-alpha plus gross-beta activities measured in Arizona at the Puerco River near Chambers and the Little Colorado River at Cameron have exceeded Arizona's Maximum Allowable Limit of 30 pCil^{-1} for all waters released from external sources in unrestricted areas by over 2 orders of magnitude (Gray & Webb, 1991). In 1987, the relative impacts of uranium-mining operations and natural processes on water quality in the Little Colorado River Basin were poorly understood. Many inhabitants of this sparsely populated region, which is largely on the Navajo Indian Reservation, were concerned that the limited water supplies they depend on--shallow groundwater for domestic use and a combination of shallow groundwater and surface water for livestock watering and forage crop irrigation--might be unfit for use.

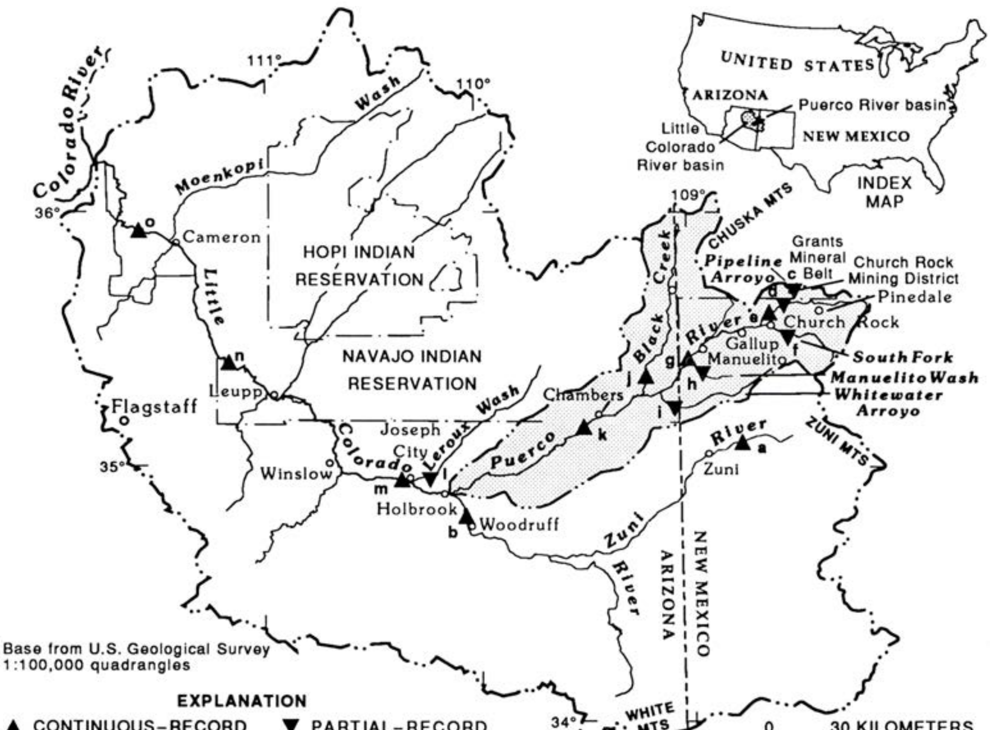

FIG. 1 Little Colorado River and Puerco River basins. See Table 1 for streamgauges denoted by lowercase letters.

Climate and Hydrology

The Little Colorado River is an ephemeral stream throughout most its 573-km length. It originates in the White Mountains of east-central Arizona and descends 1900 m before joining the Colorado River. The climate in the basin is arid in the lower elevations and semiarid to subhumid in the uplands and has a mean annual precipitation range of about 200 mm near Cameron, Arizona, to about 800 mm at the basin divide south of Winslow, Arizona. Daily average temperatures in the basin range from -3 to 27°C. Peak runoff typically occurs in March and April from snowmelt and rainfall or in July and August from thunderstorms.

The Puerco River basin drains about 7800 km^2 of the northeastern part of the Little Colorado River basin (Fig. 1). The Puerco River originates in the Chuska and Zuni Mountains of New Mexico and flows southwest about 225 km to the Little Colorado River near Holbrook, Arizona. Peak runoff in the Puerco River usually occurs from flash floods in response to summer thunderstorms. Before the 1950s, the Puerco River was an ephemeral stream. For most of the period between the 1950s to 1986, Puerco River streamflow from the mouth of the Pipeline Arroyo to past the State line of Arizona and New Mexico changed from ephemeral to perennial. The principal sources of perennial streamflow were effluent from dewatering of deep uranium-mine shafts in the CRMD and effluent discharged from the sewage-treatment plant in Gallup. In the absence of runoff, effluent typically infiltrated the alluvium within a few kilometers downstream from Chambers, Arizona.

Extremely large suspended-sediment concentrations occur in the Little Colorado River (Beverage & Culbertson, 1964) and Puerco River basins. For example, suspended sediment in three samples collected in 1957-1958 at the USGS streamgauge near Cameron, Arizona (Fig. 1), totalled 42%, 44%, and 62% sediment by weight. Suspended-sediment concentrations monitored at USGS streamgauges in 1988-1991 commonly exceeded 10% by weight in the Puerco River and Little Colorado River below the mouth of the Puerco River.

MONITORING RADIONUCLIDE AND SUSPENDED-SEDIMENT TRANSPORT

Fluvial processes are the primary mechanism for transport and redistribution of radionuclides and metals at the earth's surface (Graf, 1990). Most longer lived radionuclides in the uranium-238 and thorium-232 decay series tend to sorb strongly to sediments in pH's ranging from 7.5 to 9.0 under oxidizing conditions--conditions prevalent in runoff in the region. These facts, coupled with historically large concentrations of suspended sediments in runoff, led to the design of a monitoring network with a main focus on collection and analysis of fluvial sediments and sorbed constituents.

Data-Collection Network

The data-collection network was developed to accommodate the climatic, hydrologic, physical, and spatial characteristics of the study area. Continuous-record streamgauges were used at sites where data on radionuclide and suspended-sediment concentrations and transport were needed for each runoff period. Partial-record streamgauges were used at sites where only instantaneous concentration and discharge data were needed at discrete points on the hydrograph.

Figure 1 shows the distribution of nine continuous-record and six partial-record streamgauges used for the study. Table 1 lists streamgauge drainage areas and river kilometers downstream from the CRMD. All but three of the continuous-record sites--on Black Creek, Zuni River, and Little Colorado River at Woodruff, Arizona--and four of the partial-record sites--on South Fork Puerco River, Manuelito Wash, Whitewater Arroyo, and Leroux Wash--are located downstream from the CRMD. Data from these seven sites are used to define radionuclide concentrations and transport from unmined areas for comparison to those downstream from uranium-mining operations.

TABLE 1 Streamgauges used to monitor radionuclide and suspended-sediment transport in the Little Colorado River Basin, Arizona and New Mexico, USA

Station Name (Number)	Gauge Type (C=Continuous Record) (P=Partial Record)	Drainage Area (km^2)	Approximate Distance Downstream from Church Rock Mining District, N. Mex (km)
(a) Zuni River above Black Rock Reservoir, N. Mex. (09386950)	C	2 196	N[1]
(b) Little Colorado River at Woodruff, Ariz. (09394500)	C	20 906	N[1]
(c) Pipeline Arroyo nearPinedale, N. Mex. (353727108312401)	P	[2]8	3
(d) Puerco River near Pinedale, N. Mex. (353644108330901)	P	[2]450	4
(e) Puerco River near Church Rock, N. Mex. (09395350)	C	500	13
(f) South Fork Puerco River at Church Rock, N. Mex. (353511108361301)	P	[2]650	N[1]
(g) Puerco River near Manuelito, N. Mex (09395630)	C	2 176	62
(h) Manuelito Wash near Manuelito N. Mex. (352450108592401)	P	[2]250	N[1]
(i) Whitewater Arroyo near Allentown, Ariz. (351515109072101)	P	378	N[1]
(j) Black Creek below West Fork Black Creek near Houk, Ariz. (09395990)	C	[2]1 680	N[1]
(k) Puerco River near Chambers, Ariz. (09396100)	C	5 584	119
(l) Leroux Wash near Holbrook, Ariz. (09397100)	P	2 077	N[1]
(m) Little Colorado River near Joseph City, Ariz. (09397300)	C	32 075	215
(n) Little Colorado River at Grand Falls, Ariz. (09401000)	C	54 908	355
(o) Little Colorado River near Cameron, Ariz. (09402000)	C	68 529	415

[1] Not downstream from Church Rock Mining District. [2] Approximate.

Continuous-record streamgauge design A schematic diagram of a continuous-record streamgauge is shown in Fig. 2. Continuous-record streamgauges have three principal components: a stage sensor, a water-sampling system, and a Synergetics[1] data-collection platform (DCP). The DCP receives input from the stage sensor, activates the water-

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[1] The use of trade or product names in this report is for identification purposes only, and does not constitute endorsement by the U.S. Geological Survey.

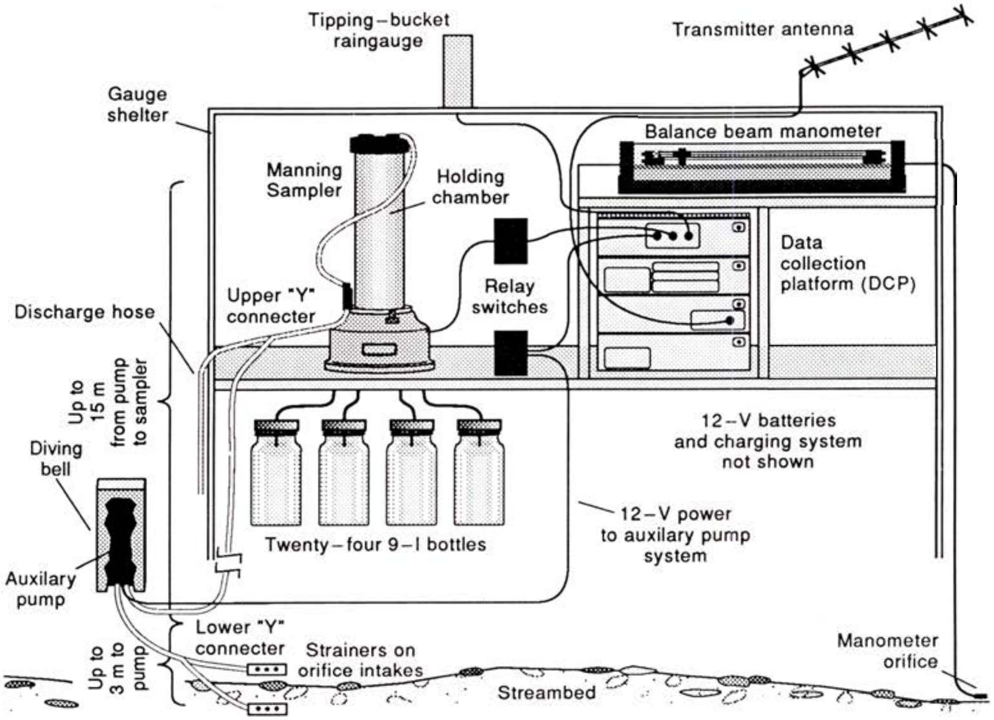

FIG. 2 Continuous–record streamgauge components.

sampling system, and transmits data on 4-h intervals to a USGS computer via satellite. Also, a tipping-bucket raingauge measures rainfall in 0.25-mm increments for input to the DCP. Electrical components operate on 12-V DC current supplied by batteries, which are charged by solar cells or 120-V AC trickle-charge converters.

Each streamgauge is equipped with one of two types of automatic stage sensors: a Fluid Data Systems balance-beam manometer or float-driven stage recorder. Shaft encoders are used with both types of stage sensors to convert the sensing instrument's shaft turn to a digital signal for input to a DCP. A streambank-mounted staffgauge serves as a visual reference to automatically sensed water levels.

The water-sampling system has two subcomponents, a Manning Environmental Corporation Model S-4050 Automatic Pumping Sampler (Manning Sampler) and an auxiliary pumping system. The Manning Sampler, housed in the gauge shelter above the high-water level, takes up to 24 discrete samples. It can be modified to fill bottles with equal preset sample volumes ranging from 1-9 l. Volumes of most samples collected were 3 l. It operates on a negative-pressure principle and has a theoretical maximum head to which it can draw water because of cavitation. In practice, the Manning Sampler ceases lifting a water-sediment mixture before cavitation occurs. Therefore, an auxiliary pump operating primarily on a positive-pressure principle was used to lift stream water to the elevation of the base of the Manning Sampler. The auxiliary pump is capable of pumping to at least 15 m of head.

The auxiliary pumping system is comprised of an auxiliary pump, 12.7-mm inner-diameter polyvinyl wire-reinforced tubes (tube), and connectors. The auxiliary pump draws a water-sediment mixture from the stream via two near-streambed intake tubes. Metal strainers perforated with dozens of 6.4-mm-diameter holes and coated on all surfaces with marine epoxy sheath intakeorifices. Use of two intakes enhances the potential to collect a representative sample and precludes failure due to plugging of a single intake.

A lower "Y" connector joins the two intake tubes to a hose connected to the low-pressure side of the auxiliary pump. A second hose connects the high-pressure side of the auxiliary pump to an upper "Y" connector at the base of the Manning Sampler. The Manning Sampler intake hose connects to one side of the upper "Y" connector, and the other side connects to a hose that discharges unused or excess water back to the stream.

The auxiliary pump--a 0.32-ls^{-1} Little Giant peristaltic pump--is located on the gauge side of the channel at a maximum 3 m above the elevation of the intakes. A metal box known as a diving bell is anchored over the auxiliary pump and prevents river water from engulfing the pump during high flows. All water-sampling system parts that contact sample water are nonmetallic.

The Manning Sampler and auxiliary pump are activated sequentially by the DCP. First, the auxiliary pump begins pumping water from the stream to the discharge-hose side of the upper "Y" connector and back to the stream. This serves to clear residual sediments and solutes from hoses. Thirty seconds after the auxiliary pump is activated, the DCP activates the Manning Sampler. The Manning Sampler sequentially purges air, draws a small aliquot of water-sediment mixture from the sampler side of the "Y" connector, then purges the aliquot. After 2 min of auxiliary-pump operation, the Manning Sampler draws a water-sediment sample into its holding chamber from the intake side of the upper "Y" connector. When the chamber fills to the prescribed limit, the Manning Sampler and auxiliary pump begin purging hose contents for 30 s, and the Manning Sampler releases the contents of the chamber to one of the 24 sample bottles. The closure of a relay as a sample bottle is filled, signals the DCP to store the sample number and its time of collection.

The DCP uses digital stage input on even 10-min intervals to control operation of the water-sampling system. When stage input to the DCP first exceeds a predetermined minimum threshold, the DCP activates the water-sampling system. Thereafter, the water-sampling system is discreetly activated up to 23 times based on time, stage, and rate-of-stage-change criteria. Figure 3 shows times of water-sampling system activation for a hydrograph from the Little Colorado River at Woodruff, Arizona.

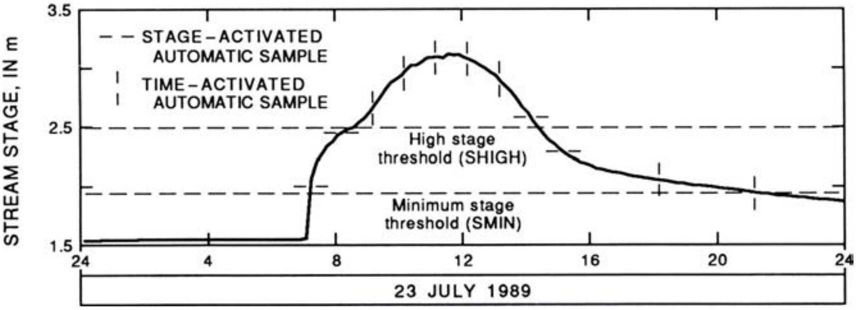

FIG. 3 Water–sampling system activation times at Little Colorado River at Woodruff, Arizona (09394500).

The algorithm that controls the water-sampling system uses four values stored by the DCP and six preprogrammed threshold values. The four DCP-stored values are the present (SPRES) and last-recorded (SLAST) stage values; and the stage value for (SACT) and duration since (TLAPSE) the last water-sampling system activation. The six preprogrammed threshold values are minimum and high stage thresholds (SMIN and SHIGH, respectively), minimum times between water-sampling system activation based on time criteria for stages below SHIGH (ΔTLOW) and at or above SHIGH (ΔTHI), and minimum values for rise (ΔRISE) and fall (ΔFALL) in stage since water-sampling system activation. All values have positive signs. When the DCP records a value less than SMIN, values for SACT and TLAPSE are reset to the minimum stage threshold and zero, respectively, so that subsequent pumping-sampler system activation occurs independently of the shape of the hydrograph from the previous runoff period.

Provided the quota of 24 samples has not been collected, the water-sampling system is activated when any of the following criteria are met:

(a) Stage exceeds minimum threshold: SLAST < SMIN and SPRES => SMIN.
(b) Stage rise: SLAST => SMIN and SPRES - SACT => ΔRISE.
(c) Stage fall: SPRES => SMIN, and SACT - SPRES => ΔFALL.
(d) Slowly varying stage, present stage at or above minimum threshold but below high threshold: SLAST => SMIN and SHIGH > SPRES => SMIN and TLAPSE => ΔTLOW.
(e) Slowly varying stage, present stage at or above high stage threshold: SLAST => SMIN and SPRES => SHIGH and TLAPSE => ΔTHI.

Stage and rainfall data on even 10-minute intervals, sampler activation times, and respective sample numbers are stored by the DCP in a circular (overwriting) memory for subsequent satellite transmission.

Partial-record streamgauge design Partial-record streamgauges are comprised of a bank of up to eight passive single-stage water-sediment samplers (single-stage samplers) and a peak-stage indicator. Figure 4 shows a schematic diagram of a bank of single-stage samplers. Banks of single-stage samplers are mounted on stable features in the channel, including bridge abutments and piers, bedrock outcrops, and previously installed channel-mounted streamgauge components.

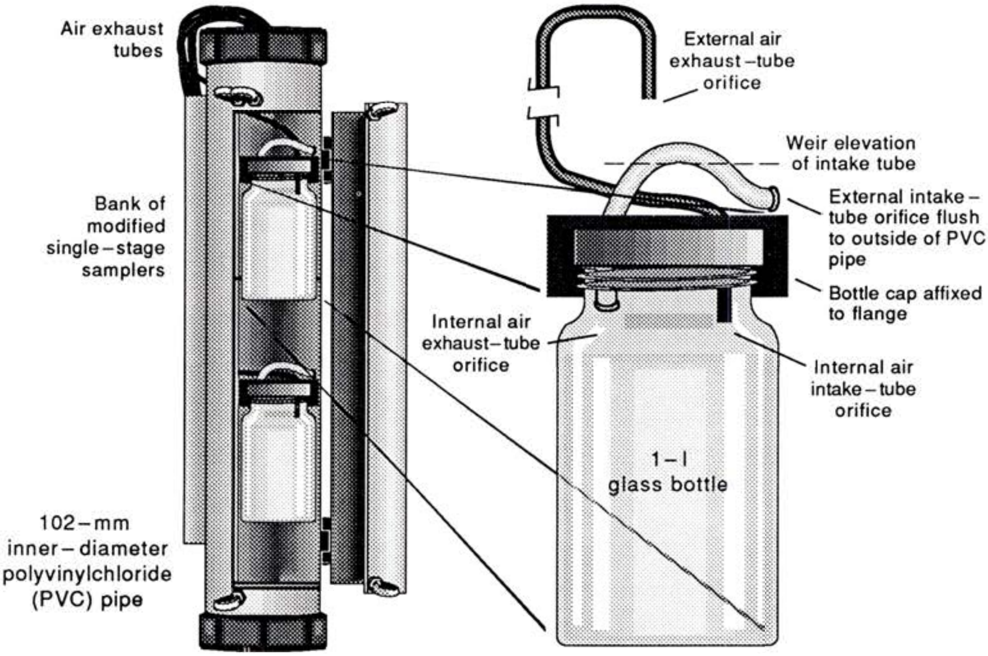

FIG. 4 Modified single-stage sampler (Gray and Fisk, 1992).

Single-stage samplers are designed to obtain a sample of the water-sediment mixture from near the water surface on the rising phase of streamflow. Those designed for this study are a modification of the U-59 series single-stage sampler developed by the Subcommittee on Sedimentation (1961). A U-59 single-stage sampler is comprised of an intake tube and air exhaust tube, which extend 10 and 50 mm, respectively, into a sample bottle through holes in a rubber stopper. The intake and air exhaust tubes are made of 6.3-mm inner-diameter copper tubing. The rubber stopper fits the mouth of a 0.47-l glass sample bottle so that the only means for entry of water and exhaust of air is through the intake and air exhaust tubes, respectively.

When total water head incident at the external intake-tube orifice exceeds the elevation of the inside top arch of the intake tube (weir elevation), water siphons through the intake tube into the bottle. Siphoning will continue as long as:

(a) stage remains above the intake orifice,
(b) total water head incident on the external intake-tube orifice exceeds that at the external air exhaust-tube orifice, and
(c) the water level in the bottle is below the elevation of the internal air exhaust-tube orifice.

When the water level in the bottle touches the internal air exhaust-tube orifice, siphoning of water into the bottle should stop. However, results from field applications indicate that circulation of the water-sediment mixture often occurs after the bottle is filled. This occurs either through the intake and air exhaust tubes and (or) as a result of flow past a failed rubber stopper seal. Either mechanism of circulation may result in the entry of heavily sediment-laden water to the bottle and loss of water containing less sediment. When water circulates, unrepresentatively large concentrations of sediment and sorbed-constituents normally result.

Several modifications were made to the U-59 series single-stage sampler to minimize the potential for water circulation and to otherwise better adapt it for use in ephemeral streams in the Little Colorado River basin. To minimize the potential for water circulation, a narrower (3.2-mm inner-diameter) air exhaust tube was extended to the highest elevation feasible for the site, thereby reducing the potential for the external air exhaust-tube orifice to be inundated. Air exhaust-tube orifices extend to elevations as much as 3 m over the sample bottle. Additionally, internal intake-tube and air exhaust-tube orifices extend about 10 mm and 25 mm into the bottle, respectively. After water in a bottle reaches the internal air exhaust-tube orifice, water rises in the air exhaust tube to an elevation equal to the total head incident on the external-intake orifice. As stage falls, a maximum of about 24 ml of sample water reenters the bottle from the air exhaust tube. Even if the equivalent of this quantity of sample is not collected representatively, its effect on the representativeness of the 1-l sample is likely to be inconsequential.

Another modification entails use of a screw-top 1-l glass bottle to provide a more positive seal to minimize leakage past the cap and to collect larger samples. Silicone grease is used to improve the seal between the bottle threads and the cap.

Runoff in ephemeral streams in the Little Colorado River basin typically conveys large quantities of debris, particularly on the rising phase. Single-stage samplers were modified to better adapt them to these conditions by arranging them vertically inside a protective polyvinyl chloride (PVC) 102-mm inner-diameter pipe capped on both ends. Screw-top bottle caps are permanently affixed to flanges mounted in the PVC pipe. External intake orifices are oriented downward at about a 45° angle, affixed flush to the outside of the PVC pipe, and oriented perpendicular to flow. External air exhaust tubes terminate downward in the tube's top cap. The absence of protruding tubes from a bank of modified single-stage samplers reduces the potential for debris to alter its performance. Hinged doors with locks provide access to the sample bottles.

All parts of a bank of modified single-stage samplers contacting sample water are made of plastic except for the glass sample bottle. This modification precludes contamination of sample contents by metals.

Field Methods and Sample Processing

Streamgauges are serviced on a routine basis using methods described by Rantz & others (1982) and methods necessitated by specialized gauge instrumentation. Routine servicing normally involves checking instrumentation to maximize its preparedness for operation during runoff.

When a continuous-record streamgauge is visited during runoff, the following procedure is followed:

(a) Check gauge instrumentation to ensure functionality.
(b) If stage is above the intakes, then manually activate the pumping-sampler system.
(c) Manually collect a flow-integrated streamflow sample by methods described by the USGS (Sylvester, M. A., Kister, L. R., & Garrett, W. B. written commun., 1990) and Edwards & Glysson (1988). Additionally, measure in-stream values for water temperature, pH, specific conductance, dissolved oxygen, and alkalinity.
(d) Repeat (b).
(e) Measure discharge using methods described by Rantz & others (1982).
(f) Repeat (a).
(g) If stage has changed significantly but remains above the intakes, then repeat sequence (b)-(f).
(h) Remove all samples from the gauge shelter and replace with empty bottles.

When a partial-record streamgauge is visited during runoff, a manual flow-integrated sample is collected and discharge is measured. When streamgauges are visited after runoff, all samples are removed and capped, and sampler parts are cleaned and inspected for functionality.

Water-sediment samples are transported to field headquarters and processed for laboratory analyses of suspended-sediment concentrations and particle-size distributions and of concentrations of selected radionuclides. Samples collected automatically from continuous-record streamgauges are processed for individual analyses as discrete points on a runoff hydrograph or to derive a single sample representative of flow during a sampling period. Samples from partial-record streamgauges are processed for use as point data for comparison to in-stream water-quality standards and to calculate instantaneous suspended-sediment and radionuclide transport at predetermined stages.

Because samples normally contain 5%-20% sediment by weight, special techniques are used to separate sediments from water to enable discrete chemical analyses on the suspended and dissolved phases. The following procedure is followed for processing samples used as point data:

(a) A 250-ml aliquot is collected by splitting the original sample through a Jones Splitter or USGS Cone Splitter. The former splits water-sediment samples in two equal-volume, representative aliquots. The latter splits samples into 10 equal-volume, representative aliquots (Gray & deVries, 1984). The 250-ml aliquot is submitted for suspended-sediment concentration and particle-size distribution analyses.
(b) The remainder of the sample is centrifuged at 2000 revolutions min^{-1} for 6 min. The almost clear supernatant is decanted and filtered through a 0.45–μm filter for dissolved-radionuclide analyses.
(c) The residual plug of sediment is weighed, oven dried at 80°C for 24 h, and reweighed.
(d) The dried sediment is separated into three parts. One part is submitted for determinations of activities by total dissolution for uranium-238, -235, and -234; lead-210; thorium-232 and -230; and radium-226 and -228. The second part is submitted for a full suite of analyses for stable metals, also by total dissolution. The third part is stored in a plastic container for potential later use for quality control or sample reruns or to analyze for additional constituents.

A single sample representative of flow past the streamgauge during a sampling period is known as a flow composite. A flow composite requires only a single laboratory analysis of constituent concentrations per runoff period and, therefore, is significantly less expensive to analyze than a suite of samples representing points over a hydrograph. A minimum of three automatically pumped samples are required during a period of runoff to derive a flow composite.

Information needed to derive a flow composite includes the time and discharge for each sample and the time runoff started. Each sample is assigned a value for discharge and the time duration that it represents. The duration for the first sample spans the time from runoff initiation to the midpoint between times of collection for the first and second samples. Duration for the last sample is calculated to be equal to the difference in collection times for the last two samples. Durations for each of the remaining samples is calculated as half the time from collection of the previous sample to half the time to the subsequent sample's collection.

Durations represented by each sample are multiplied by their respective instantaneous discharges to calculate the volume of flow that passed the streamgauge during each sample interval. Flow volumes are summed to derive runoff volume for the period represented by the samples. A representative aliquot from each sample is then obtained using the Jones Splitter or USGS Cone Splitter proportional to the part of runoff for the period that it represents. Aliquots are combined into a single sample container, processed, and analyzed in a manner similar to a sample used as point data. Data on radionuclide and suspended-sediment concentrations derived by the above methods are used to calculate transport of these constituents.

Methods for Data Management and Analysis

Computation of radionuclide and suspended-sediment transport requires data on water discharge and concentrations of suspended sediment and selected radionuclides. Techniques for management and analysis of suspended-sediment data used for this study have been adopted nationwide by the USGS.

Time series and instantaneous data are merged to compute water, suspended-sediment, and radionuclide discharges. Stage and rainfall data are transmitted on 4-h intervals via a Geostationary Operational Environmental Satellite (GOES) to a USGS Earth Receiving Station, automatically reformatted, and stored on a USGS computer. Figure 5 is a conceptual diagram showing how data are transmitted, stored, and processed. Instantaneous data on suspended-sediment and radionuclide concentrations from samples are obtained from USGS laboratories and stored on the USGS computer. Concentrations of radionuclides are compared to water-quality standards. Continuous records of water discharge are computed from stage data and a stage-discharge rating for the site (Rantz & others, 1982) using the Automated Data Processing System (Dempster, 1990). Continuous records of suspended-sediment discharges are calculated from unit values of discharge and instantaneous values of suspended-sediment concentrations using methods described by Porterfield (1972) and the Sediment Records Calculation (SEDCALC) software developed by Gray & McElhone (1990). SEDCALC is an interactive program that accepts unit discharges and instantaneous suspended-sediment concentrations and calculates unit and daily suspended-sediment discharges.

Transport of selected constituents is calculated by one or more of the following methods:

(a) By methods described by Porterfield (1972) and SEDCALC.
(b) By multiplying suspended-sediment transport by an appropriate value of proportionality if concentrations of selected constituents at a streamgauge are determined to be directly proportional to associated suspended-sediment concentrations.
(c) By multiplying constituent concentrations from a flow composite by the flow volume it represents.

Use of these computational methods for radionuclides is predicated on the assumption that decay rates of radionuclides being studied--with half lives ranging from thousands

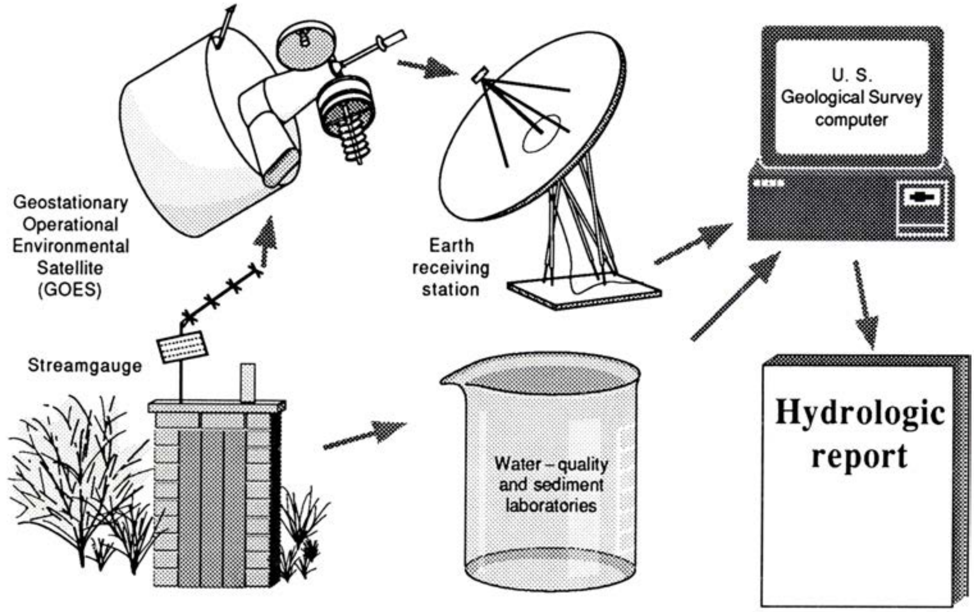

FIG. 5 Conceptual diagram showing how hydrologic data are transmitted, stored, and processed.

to billions of years--are insignificant with respect to time scales on which runoff occurred and could, therefore, be treated as conservative constituents for computational purposes. Figure 6 shows temporal variations in discharge and concentrations of suspended sediment, dissolved uranium, and suspended uranium for a runoff period on the Little

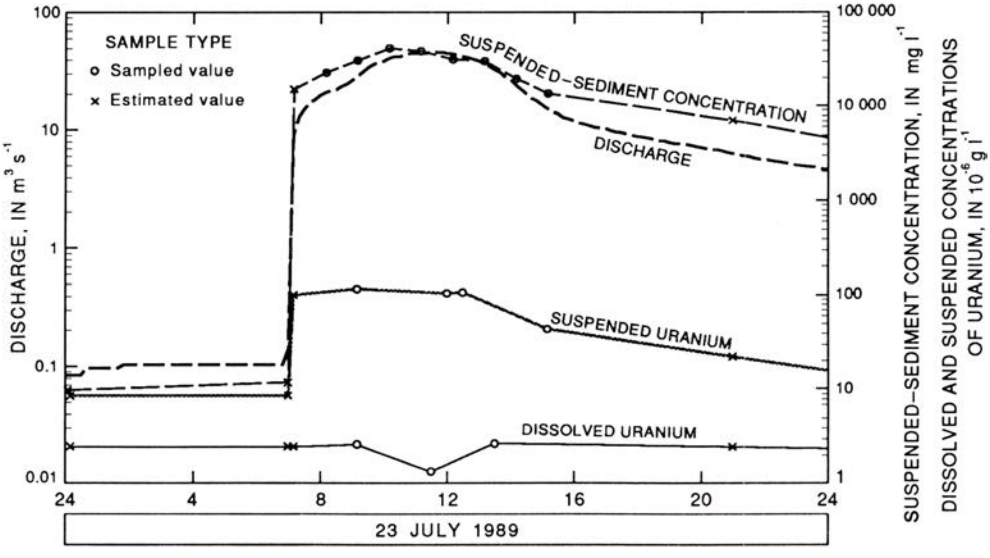

FIG. 6 Temporal variations in discharge and concentrations of suspended sediment and suspended and dissolved uranium at Little Colorado River at Woodruff, Arizona (09394500).

Colorado River at Woodruff, Arizona. As a quality-control measure, radionuclide and suspended-sediment transport for each of several runoff periods determined from instantaneous data and from a flow composite are compared. Comparison of the paired data enables determinations of the validity of using a flow composite for estimating constituent transport. As an additional quality-assurance measure, approximately 15% of samples sent to laboratories are duplicate or blank samples to better estimate variability in sample-collection and (or) processing techniques and (or) laboratory analytical techniques.

ACKNOWLEDGEMENTS The authors are grateful to Edwin K. Swanson of the Arizona Department of Environmental Quality (ADEQ) for his enthusiastic support in developing new methods for hydrologic-data collection in the American Southwest. Also, we thank the Office of Navajo and Hopi Indian Relocation, the New Mexico Environment Department, and ADEQ for their financial support, without which the study would not have taken place.

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