HOW TECHNOLOGY INNOVATIONS SHAPED THE DEVELOPMENT AND DELIVERY OF 21ST CENTURY REAL-TIME WATER-QUALITY DATA

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USGS

Four Main Technology Innovations

- **Instrument Revolution in Chemistry**
- **Data Recorders, Telemetry, and Communication Systems**
- **Data Processing Software and Water Information Systems**
- **Data Dissemination on the Internet**

Definitions of a Few Common Terms

- **Continuous water-quality (CWQ) monitoring.** High-frequency water-quality monitoring with sensors at the sub-daily scale over a period of months to years.
- **Near Real Time (RT) data.** Near RT refers to data transmitted at a slightly slower rate relative to that of data collection.
- **Real Time (RT) data.** RT data are transmitted at the same rate relative to that of data collection.
- **Water-quality monitor (WQM).** A monitoring platform collecting continuous water-quality data.

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Why Monitor Water Quality at Sub-Daily Frequencies?

To address issues of immediate concern

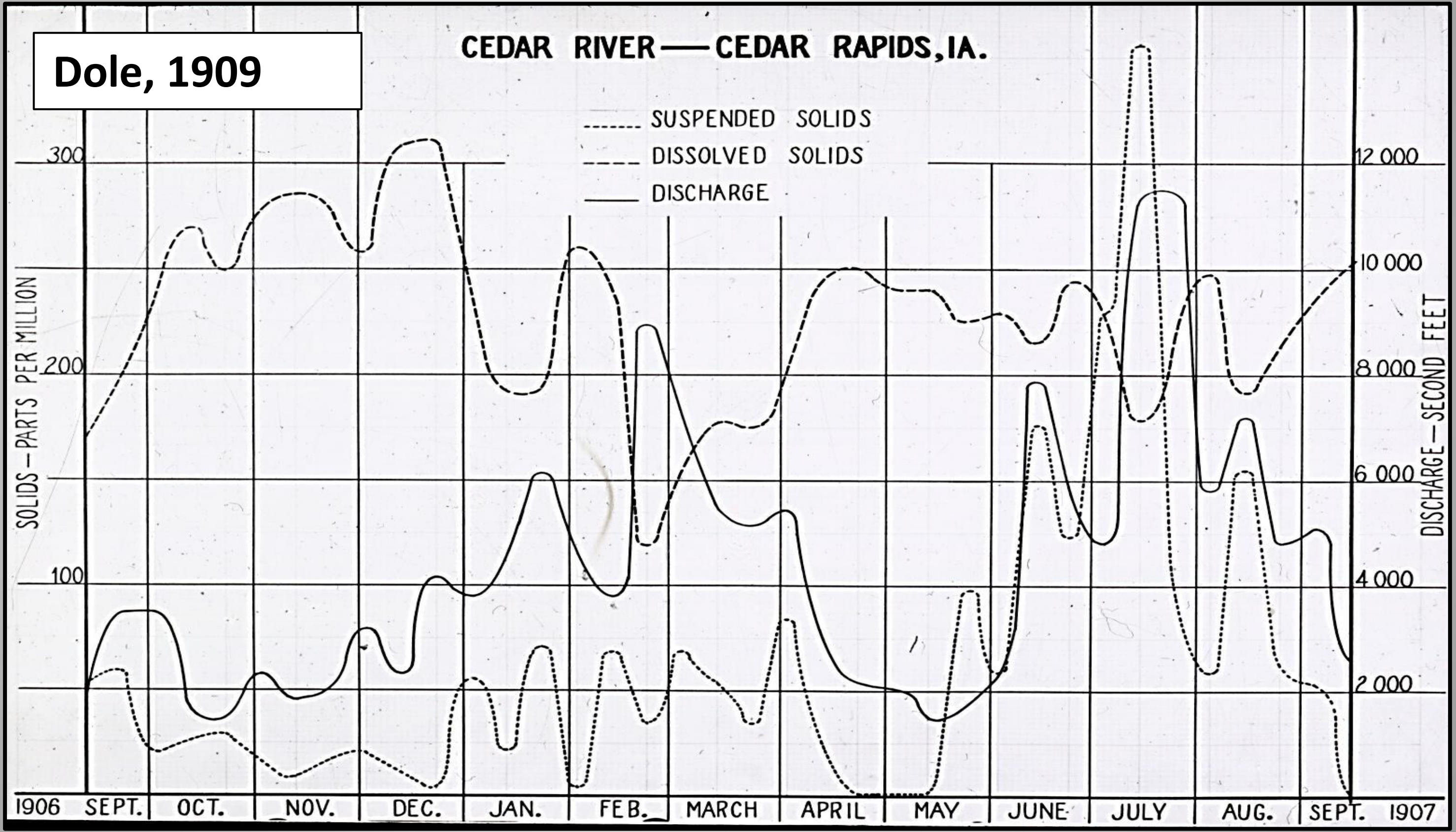
- **In aquaculture, drinking water, and wastewater treatment**
- **To improve understanding of short- and long-term processes**
- **For spill detection, monitoring, and response**
- **Better understand fate of water contaminants**

USGS

Technavio, 2017

A Brief History of Technologies Leading to the Development of CWQ Monitoring

Daily Water-Quality Samples from the Cedar River, Iowa in 1906-07 Provide an Early Representation of Time Series Data



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Before 1950 almost all Water-Quality Analyses were made in Laboratories

pH Meter

Wheatstone Bridge

Wet Chemistry Methods, 1800-1930

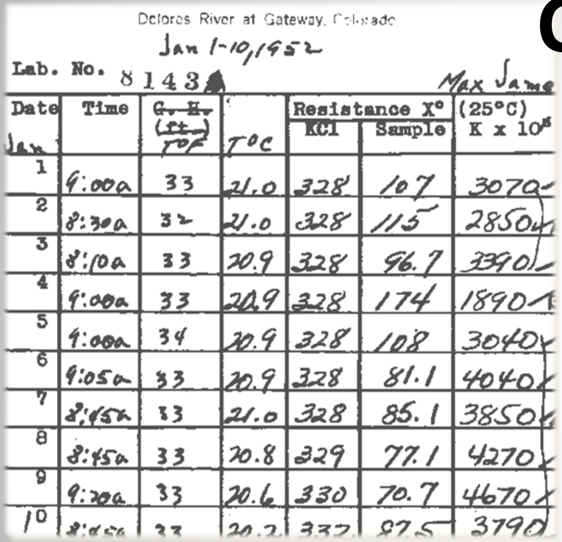
1800 | 1850 | 1900 | 1950

USGS

Daily Sampling Evolved to Continuous Monitoring

A

B



Dolores River at Gateway, Colorado

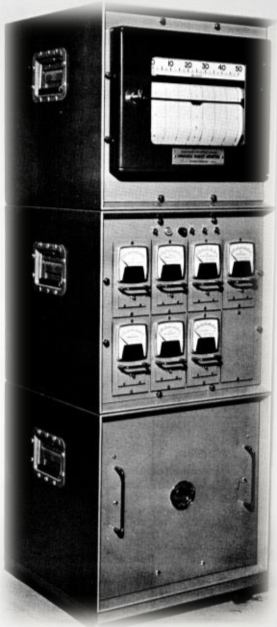
Jan 1-10, 1952

Lab. No. 8143

Max Jame

Date Jan	Time	G. H. (ft.) T°F	T°C	Resistance X° KCl	Resistance X° Sample	(25°C) K x 10^5
1	9:00a	33	21.0	328	107	3070
2	8:30a	32	21.0	328	115	2850
3	8:10a	33	20.9	328	96.7	3390
4	9:00a	33	20.9	328	174	1890
5	9:00a	34	20.9	328	108	3040
6	9:05a	33	20.9	328	81.1	4040
7	8:45a	33	21.0	328	85.1	3850
8	8:45a	33	20.8	329	77.1	4270
9	9:20a	33	20.6	330	70.7	4670
10	[illegible]	33	[illegible]	[illegible]	[illegible]	3790

C



D

1940 1960 1980

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Key Developments in Monitoring Technology And Data Reliability

Laboratory Instruments were the Basis for the First Portable Field Meters

A

B

C

D

A. DR Colorimeter for Nutrients

B. Field Fluorometer (Dyes, FChl, FDOM)

C. Turbidity Meter

D. Dissolved Oxygen with Water Temperature Thermistor, ORP Sensors

E. Ion Selective Electrodes

1950 | 1960

Multi-Parameter Sondes, Acoustic Sediment ADVMs, and Chemical Analyzers Represent Major Innovations in CWQ monitoring

Submersible 4-parameter sonde

ADVM for Acoustic Backscatter

Optical DO

More Sensors for Sondes TU, FCHL, Optical DO, UV-Nitrate (2000-06)

Automated Submersible Wet Chemical Nutrient Analyzer

1960		1970		1980		1990		2000	

USGS

(Palmer, 1970; Wood, 2014; YSI, Inc., 2015; Systea SpA, undated)

Wet-Chemical Sensors, Optical Nitrate Sensors, and Multi-Parameter Sondes are Some of the Newer Reliable Sensor Systems

A. Wet-Chemical Phosphate Sensor

B. Optical Nitrate Sensor

C. Multiparameter Sonde

USGS

Shoda et al., 2015

Innovations in Sensors have led to Longer Intervals between Service Visits and to Deployments in Remote Locations

Shoda et al., 2015

Anti-Fouling Mechanisms

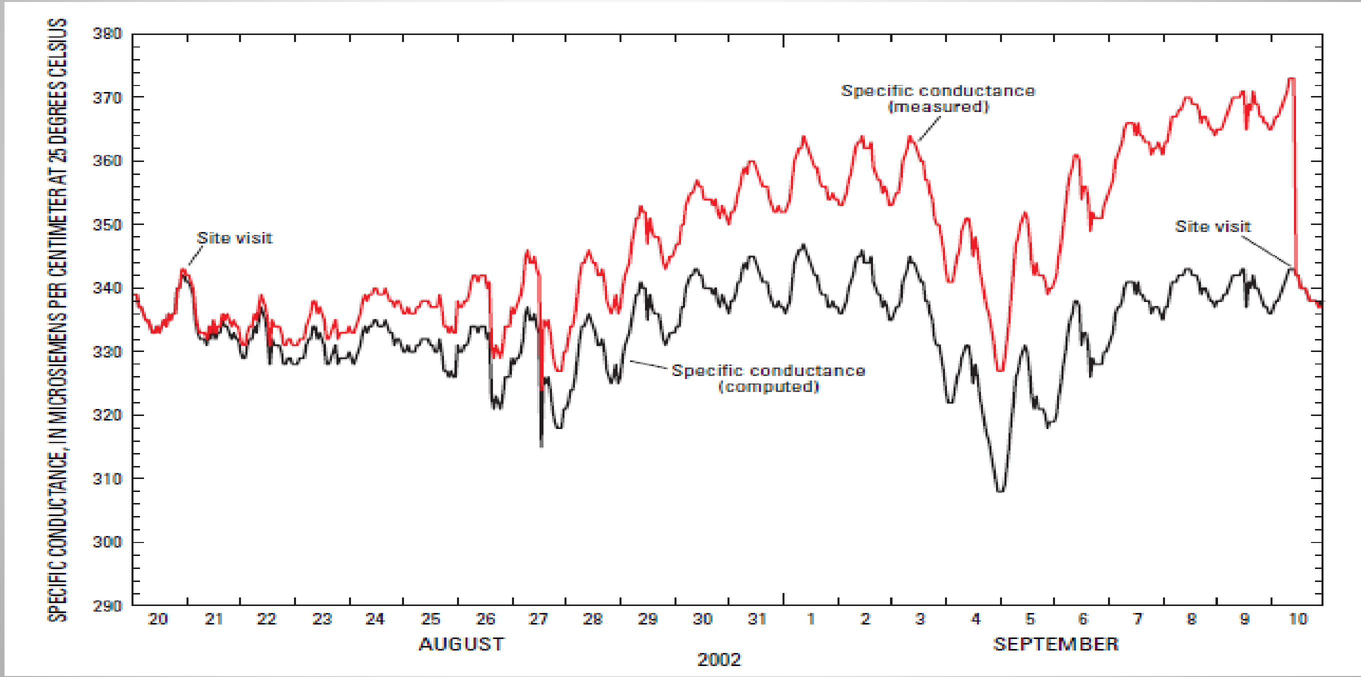
- Wipers and brushes
- Pressure pulses
- Antimicrobial components like copper and tributyl tin
- Limited contact time during immersion

Submersible Sensors

Longer Battery Life

Solar Power to Recharge Batteries

Standardized Methods and Guidelines are a Key to Reliable CWQ data



Wagner et al., 2006

Guidelines and Procedures for Water-Quality Monitors

Smoot and Blakey, 1966

U. S. DEPARTMENT OF THE INTERIOR
Geological Survey
Water Resources Division

Systems for Monitoring and Digitally Recording Water-Quality Parameters

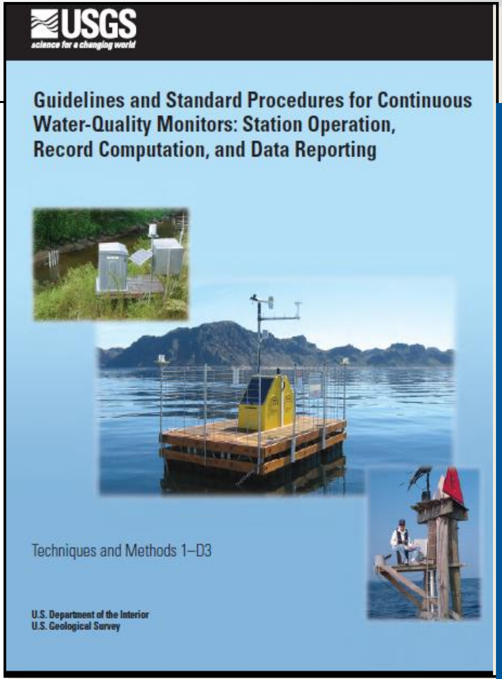
Washington, D. C.
August 1966

Gordon and Katzenbach, 1983

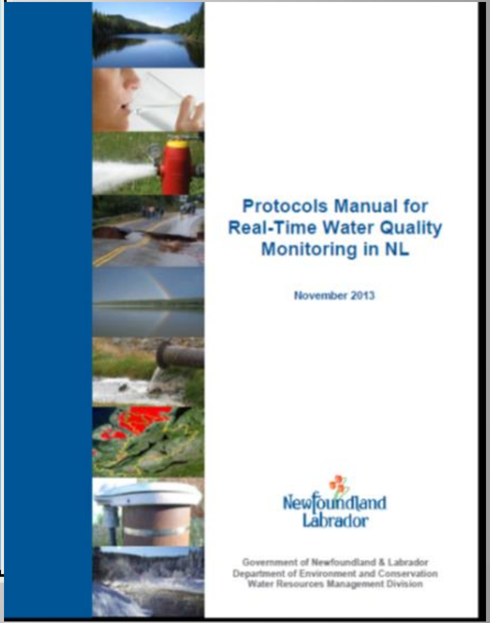
GUIDELINES FOR USE OF WATER QUALITY MONITORS

Reston, Virginia
1983

Wagner and others, 2006



Government of Newfoundland and Labrador, 2013



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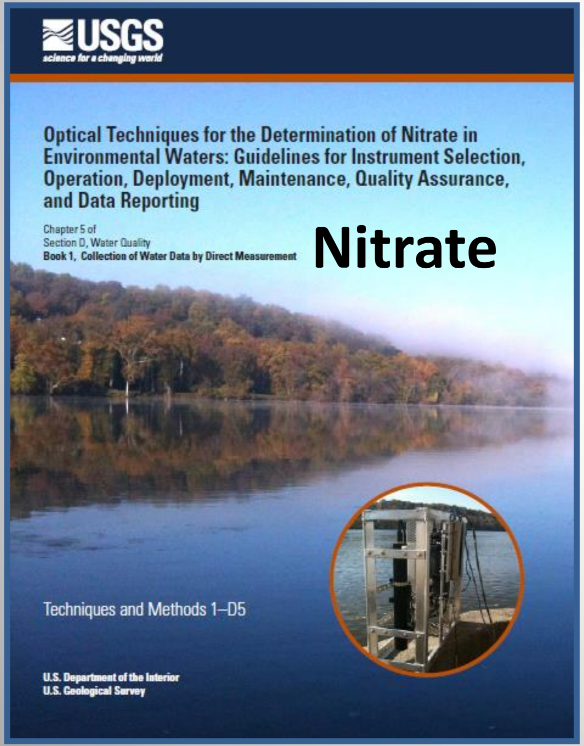
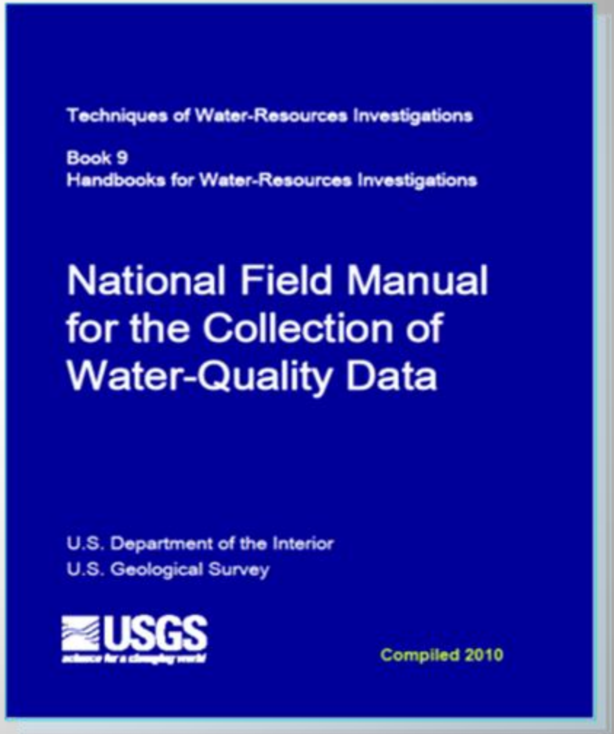
Guidelines and Procedures Cont’d.

Pellerin et al., 2013



Wilde et al., variously dated



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Key Developments in Monitoring Platforms

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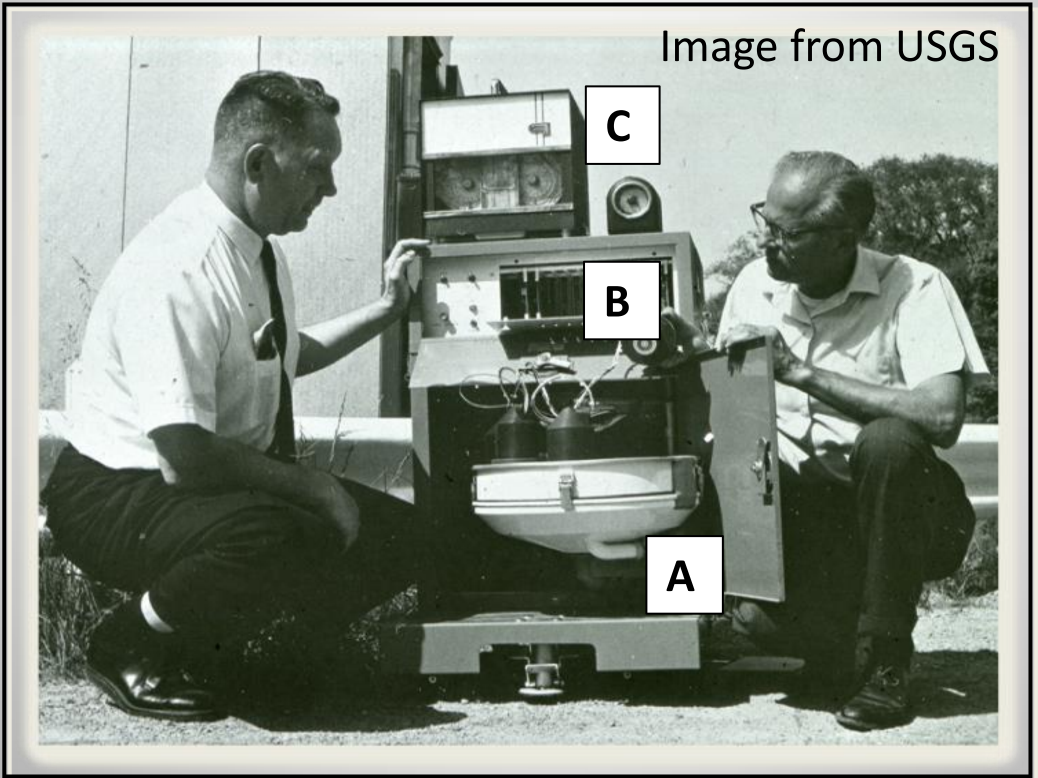
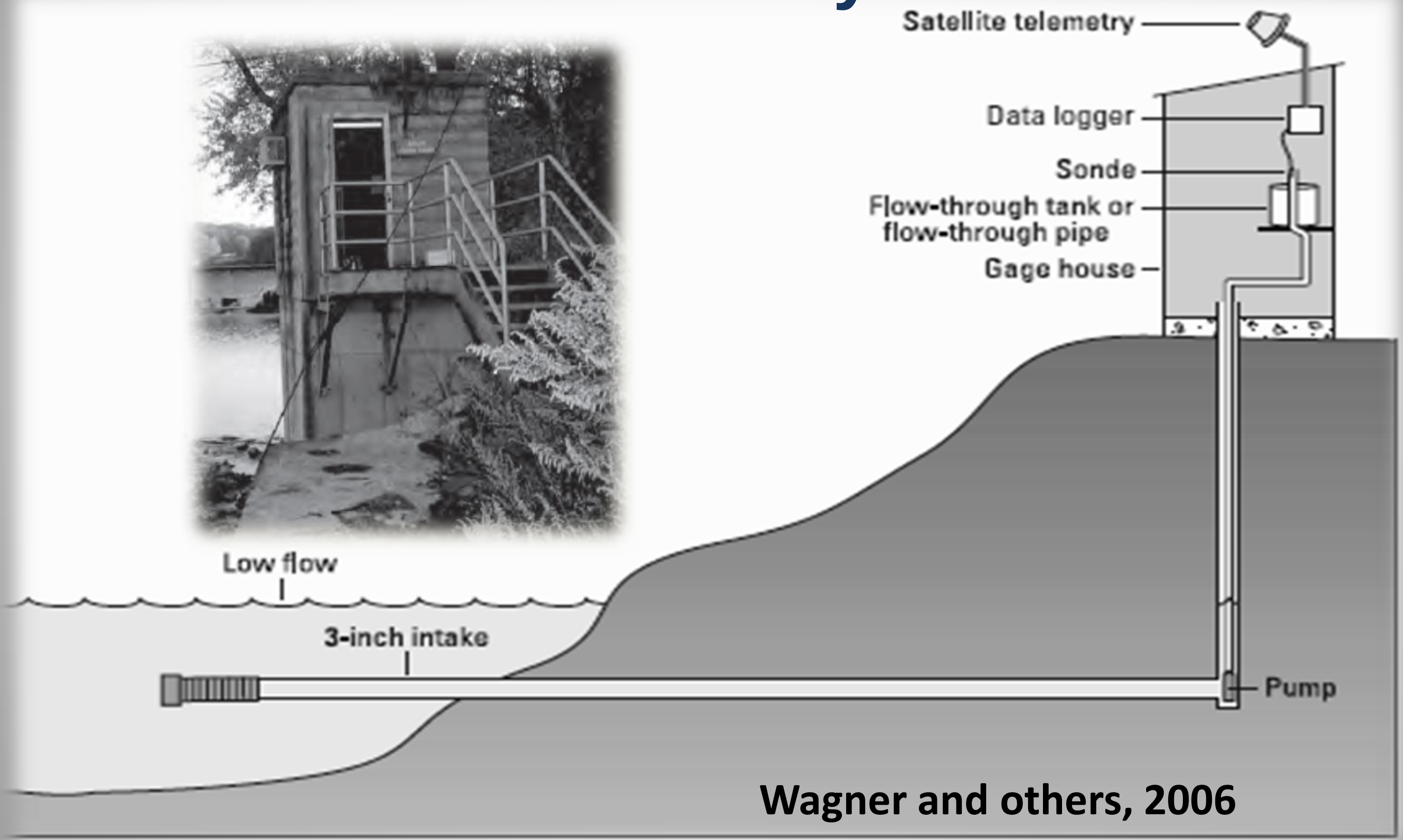
First Water-Quality Monitor- the Delaware River Estuary, 1955-62



Smoot and Blakey, 1966

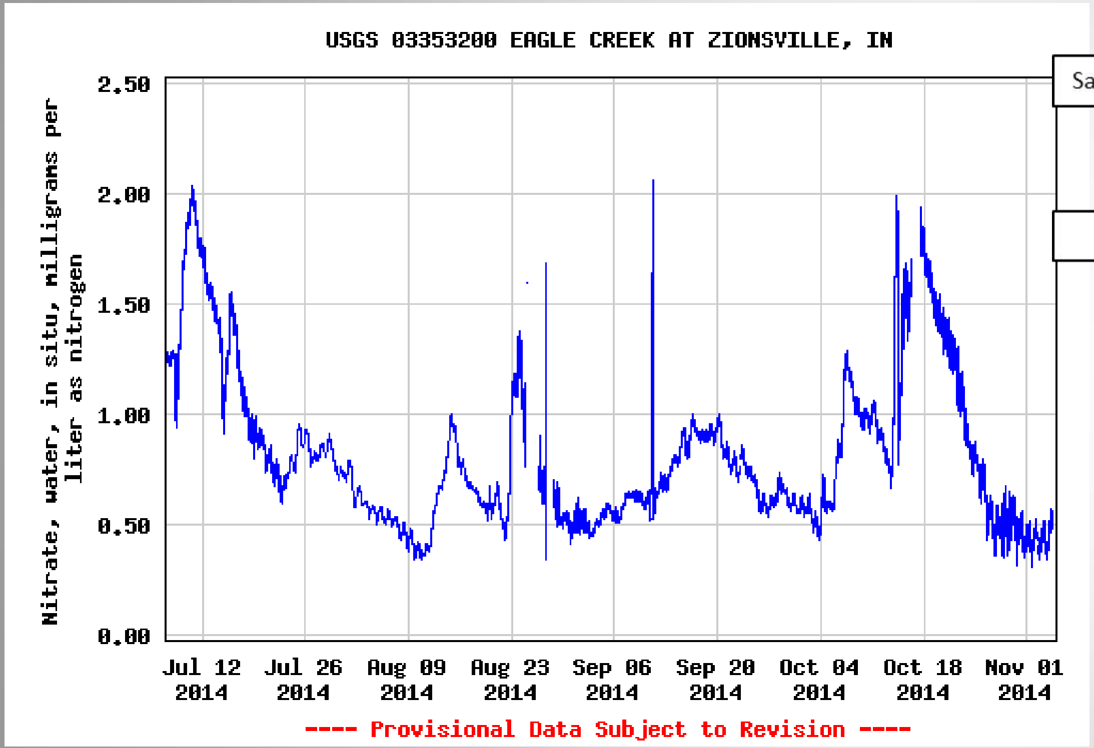
USGS

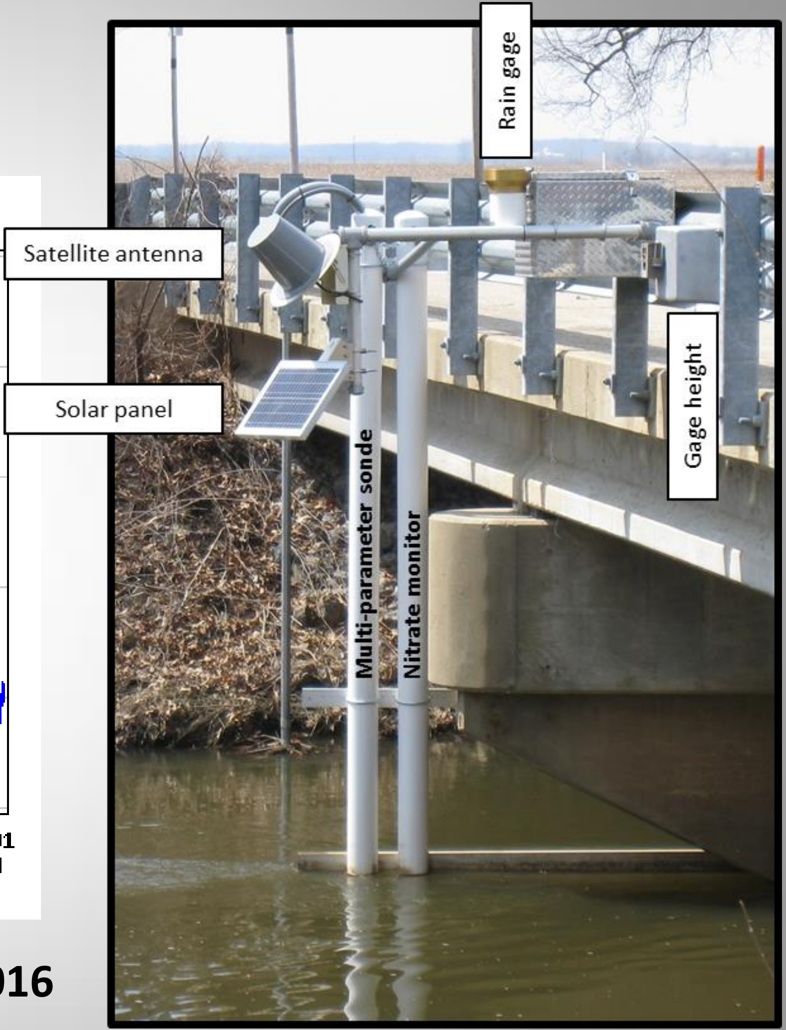
Traditional Stationary Platforms – Pumping and Submersible Systems



Wagner and others, 2006

New Type of Sentinel Stream Monitor without Shelter in Indiana





USGS

Shoda et al., 2016

Storm Hardened Platforms in Mississippi Sound Track Recovery and Restoration of Coastal Habitats after 2005 Hurricane Season

Mississippi Sound at Gulfport Light (301912088583300)
Rebich, 2015

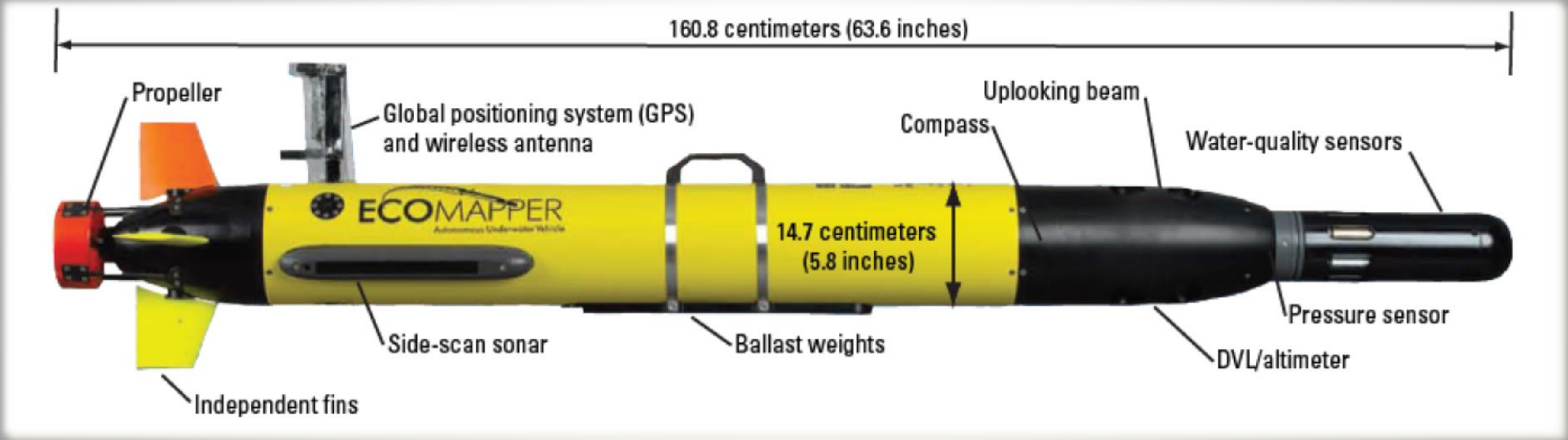
USGS

Monitoring Buoys in the San Francisco Bay-Delta are helping to track and understand the impacts of nutrient enrichment on water quality and aquatic life

USGS

Kraus et al., 2017; Photos by Bryan Downing, USGS

Mobile Platforms - Autonomous Underwater Vehicles and Pontoon Boats for Integrated Synoptic Surveys

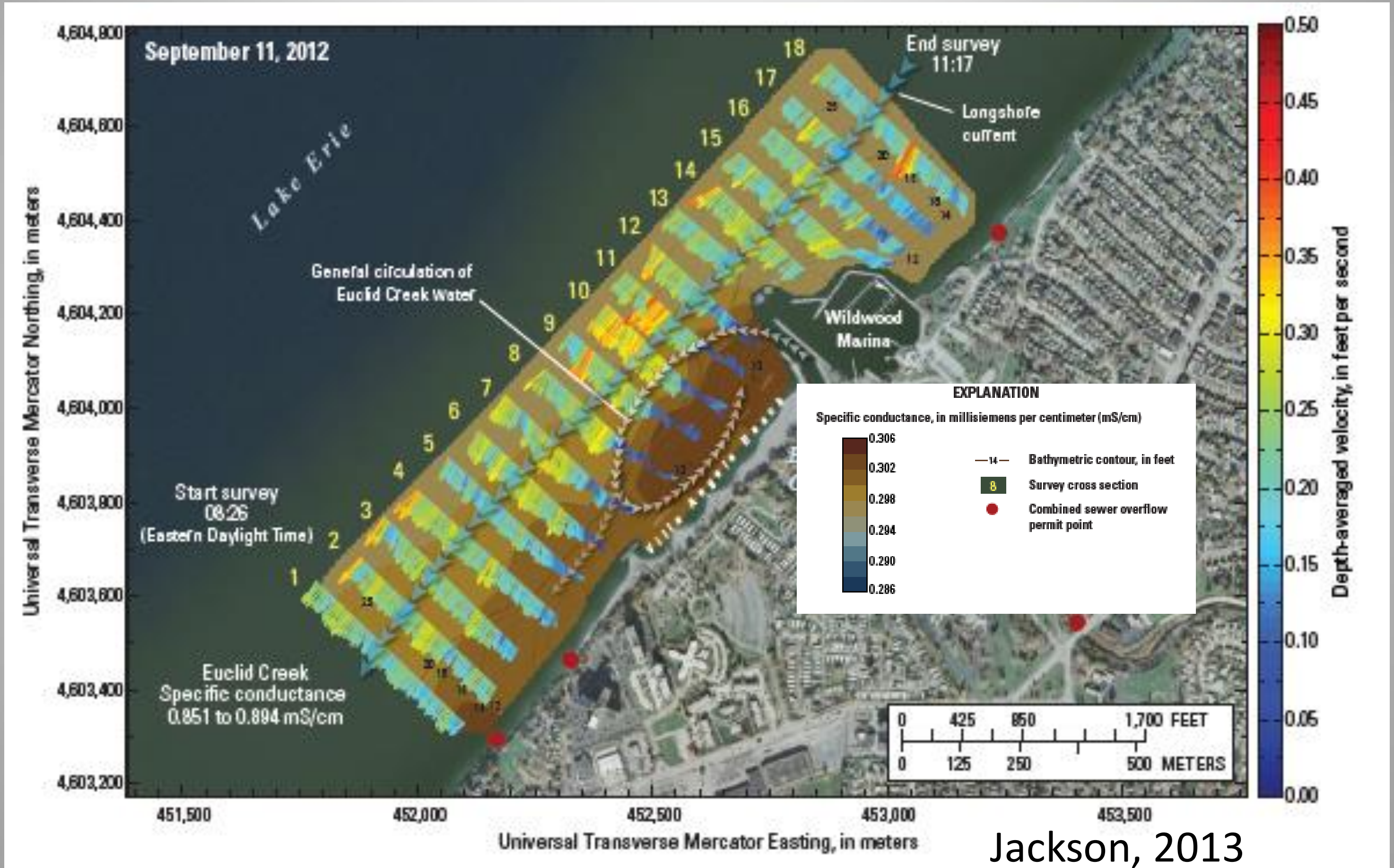


Propeller Driven Autonomous Underwater Vehicle

USGS

Jackson, 2013

Integrated Synoptic Survey in Lake Erie near Cleveland, Oh. Supports Near RT Forecasts of Beach Water Quality



Jackson, 2013

Autonomous Vehicles Track and Help Forecast Harmful Algal Blooms in Coastal Waters

Autonomous Pontoon Boat
Bendis, Florida Fish and Wildlife Cons.

Autonomous Glider AUV
Glasgow et al., 2004

Key Developments in Data Recorders, Telemetry, and Communication Systems

Developments in Data Storage and Transmission

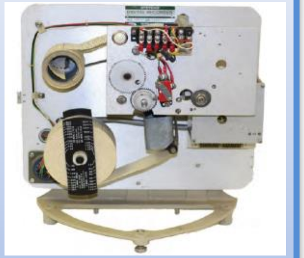
Analog Strip Chart Recorder 1900s-1960s

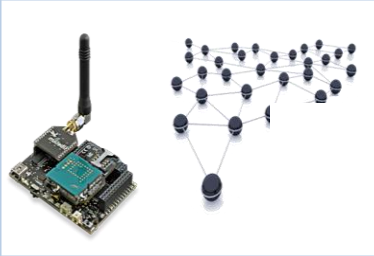
Paper Punch- Tape Digital Recorder Mid-1960s

Electronic Data Logger (EDL) 1970s

Satellite Transmission from Data-Collection Platform (DCP) 1975

Wi-Fi and Cellular Networks 2000s



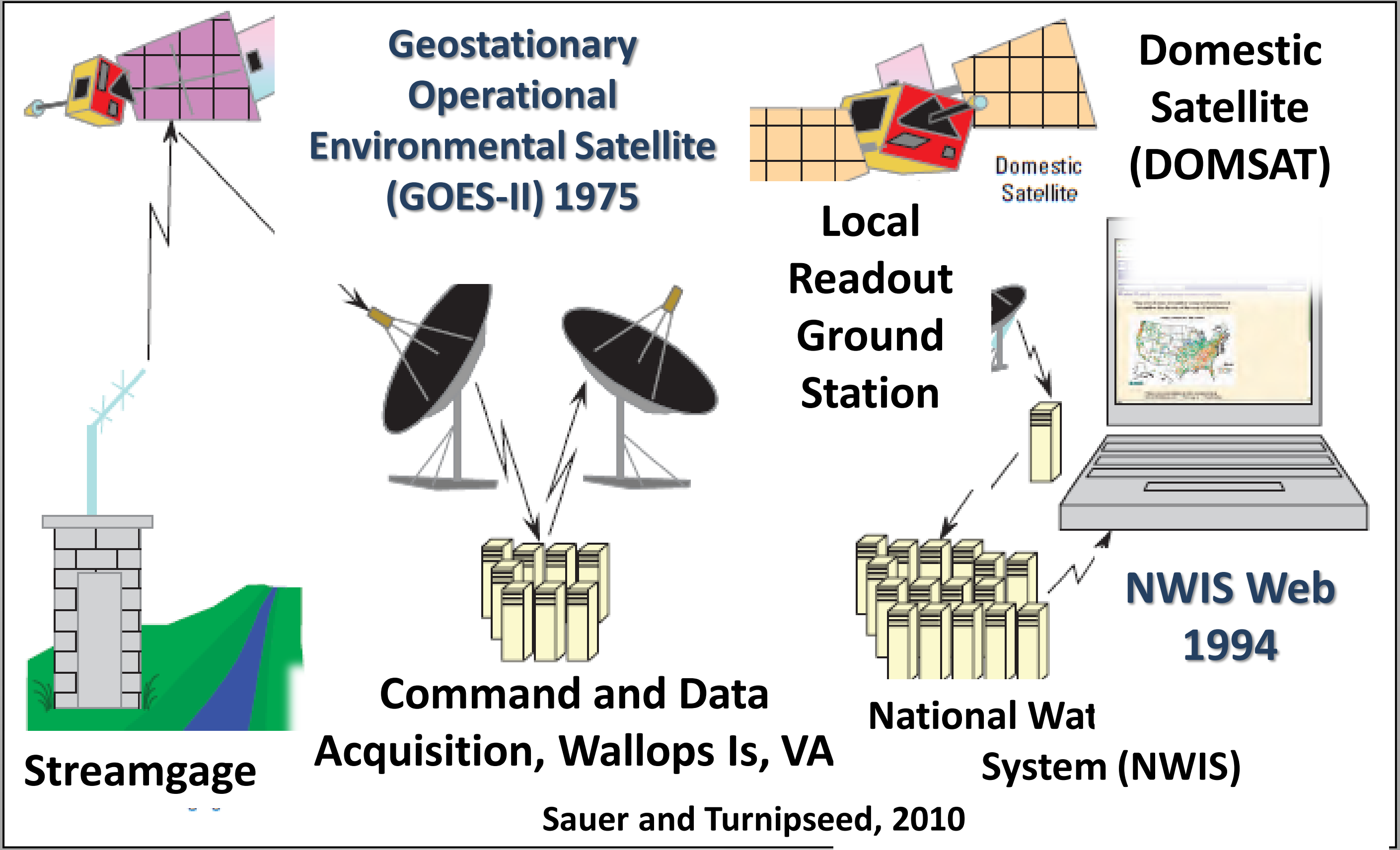


1970 | 1990 | 2000

USGS

Sauer and Turnipseed, 2010; YSI, Inc., 2015

Data Transmission from a Streamgage to the Internet



Sauer and Turnipseed, 2010

Key Developments in Data Processing Software and Water Information Systems

45-year History of Innovations in Software and Hardware for Time-Series Data at the USGS

IBM Mainframes

Installation of ADAPS Software on 45 Distributed NWIS systems

Centralized Data Processing with Cloud Storage

WATSTORE

NWIS-I ADAPS

NWIS-II ADAPS

AQUARIUS TS

1970		1980		1990		2000		2010	

USGS

USGS, 1998, 2002; Bartholoma et al, 2003; Aquatic Informatics, 2017

Software Programs or Systems are used by almost all (97%) of water monitoring organizations to manage large amounts of time series data

- **Commercial Spreadsheet Programs, 35%**
- **Custom or Home-Grown Solutions, 34%**
- **Commercial Systems, 28%**

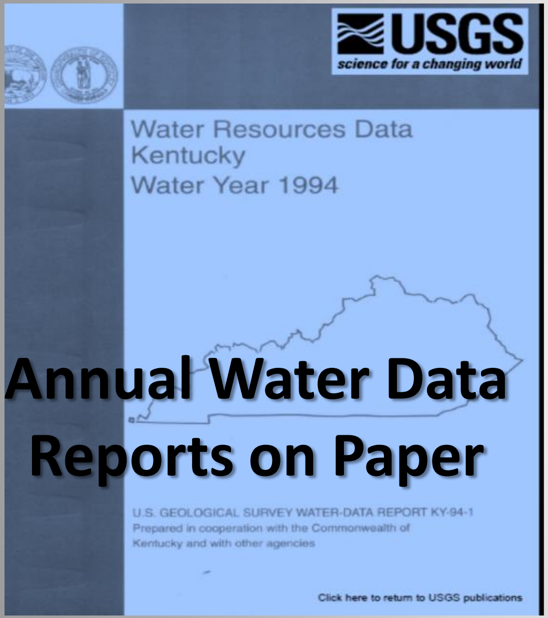
Aquatic Informatics, 2015

USGS

Key Developments in Data Dissemination on the Internet

From “on Paper” to “on Demand”

https://wdr.water.usgs.gov/



Annual Water Data Reports on Paper

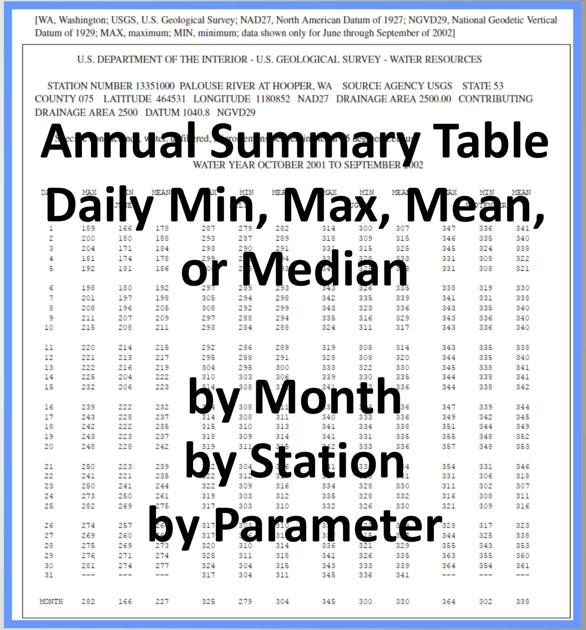
Reports on Demand

- 2014 onward

Reports On Line

- 2006-2013

Pre-2005 Reports in USGS Publications Warehouse



[WA, Washington; USGS, U.S. Geological Survey; NAD27, North American Datum of 1927; NGVD29, National Geodetic Vertical Datum of 1929; MAX, maximum; MIN, minimum; data shown only for June through September of 2002]

U.S. DEPARTMENT OF THE INTERIOR - U.S. GEOLOGICAL SURVEY - WATER RESOURCES

STATION NUMBER 13351000 PALOUSE RIVER AT HOOPER, WA SOURCE AGENCY USGS STATE 53
COUNTY 075 LATITUDE 464531 LONGITUDE 1180852 NAD27 DRAINAGE AREA 2500.00 CONTRIBUTING
DRAINAGE AREA 2500 DATUM 1040.8 NGVD29

WATER YEAR OCTOBER 2001 TO SEPTEMBER 2002

DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
		JUNE			JULY			AUGUST			SEPTEMBER	
1	189	166	178	287	279	282	314	300	307	347	336	341
2	200	180	188	293	287	289	318	309	315	346	335	340
3	204	171	184	293	290	291	331	315	325	345	324	338
4	181	174	178	299	[illegible]	[illegible]	[illegible]	328	333	331	308	322
5	192	181	186	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	331	308	321
6	198	180	192	297	289	293	343	326	335	338	319	330
7	201	197	198	305	294	298	342	335	339	341	331	338
8	208	196	205	308	292	299	343	323	336	343	335	340
9	211	207	209	297	288	294	335	316	329	343	336	340
10	215	208	211	293	284	288	324	311	317	343	336	340
11	220	214	215	292	286	289	319	308	314	343	335	338
12	221	213	217	295	288	291	328	308	320	344	335	340
13	222	216	219	304	295	300	333	322	330	345	338	341
14	225	204	222	310	303	306	339	330	335	344	338	341
15	232	206	223	[illegible]	308	[illegible]	341	[illegible]	336	344	338	342
16	239	222	232	[illegible]	308	[illegible]	[illegible]	[illegible]	336	347	339	344
17	243	228	237	314	308	311	340	333	336	349	342	345
18	242	222	235	315	310	313	341	334	338	351	344	349
19	243	223	237	318	309	314	341	331	335	355	348	352
20	248	228	242	319	311	[illegible]	[illegible]	333	336	357	348	353
21	250	223	239	[illegible]	304	[illegible]	[illegible]	[illegible]	[illegible]	354	331	346
22	241	221	235	[illegible]	312	[illegible]	[illegible]	[illegible]	[illegible]	331	306	318
23	250	241	244	322	309	316	334	328	330	311	302	307
24	273	250	261	319	303	312	335	328	332	316	308	311
25	282	269	275	317	303	310	332	326	330	321	309	316
26	274	257	[illegible]	317	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	328	317	323
27	269	260	[illegible]	317	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	344	325	338
28	275	269	273	320	310	314	336	321	329	355	343	353
29	276	271	274	325	311	318	341	326	335	363	355	360
30	281	274	277	324	304	315	343	333	339	364	354	361
31	---	---	---	317	304	311	345	336	341	---	---	---
MONTH	282	166	227	325	279	304	345	300	330	364	302	338

Annual Summary Table
Daily Min, Max, Mean, or Median

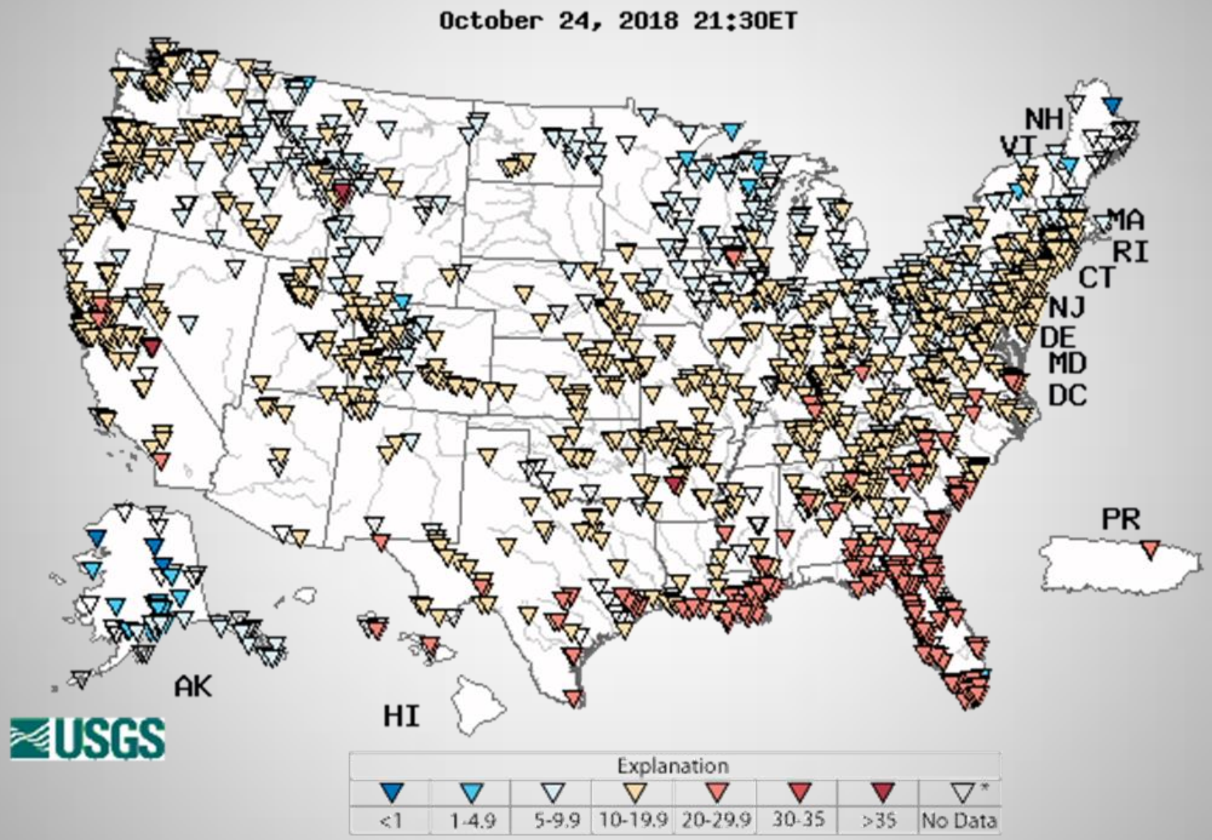
by Month
by Station
by Parameter

20th Century Paper Reports → **21st Century Electronic Reports**

USGS

Hirsch and Fisher, 2014

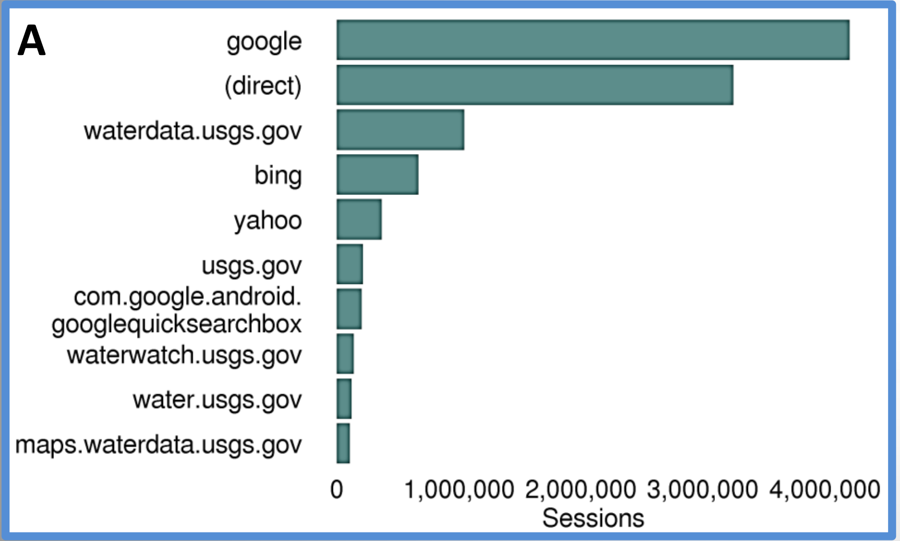
CWQ Data Displayed 24/7/365 in Near RT



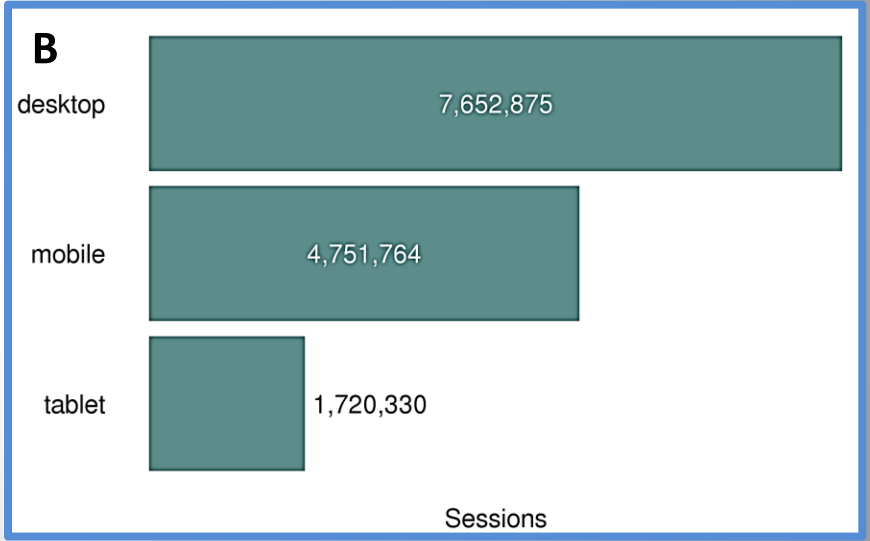
https://waterwatch.usgs.gov/wqwatch/

How Data is Accessed and Retrieved from the Internet is Evolving

Retrieval of Data by Search Engine or Web Site



Retrieval of Data by Device Type



USGS Data Analytics from NWIS Web 2018

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Advantages and Limitations of CWQ Monitoring

	Advantages	Limitations
1	Changes in water quality at the sub-daily scale are detected by continuous water-quality data	Large data sets require software system(s) for review, quality control, storage, and retrieval
2	WQMs can be deployed in a wide range of aquatic environments	Risk of damage or loss during hurricanes, floods, ice, and vandalism
3	Can inform decisions for protection of life, property, health, and operational decision making	Meeting data user expectations for uninterrupted flows of reliable and timely data are challenges
4	WQMs can provide high-resolution data with high precision and low bias	Field servicing needed to address biofouling, interferences, malfunctions, calibration drift

Advantages and Limitations, Cont'd.

	Advantages	Limitations
5	Timely data for science-based decision support	More standardized methods are needed for regulatory decision making
6	Low cost on a per measurement basis	Substantial costs for initial set-up and ongoing maintenance
7	New types of CWQ sensors are continually being developed	Fewer types of measurements available compared to laboratory methods

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Summary

New Sensors are Increasing the Types of Water Properties and Characteristics that can be Reliably Measured at High Temporal Frequency

- **Seven-parameter sondes, smart sensors, new optical sensors, and automated chemical analyzers are becoming well established technologies**
- **WQMs need guidelines for operation and quality control procedures to ensure data quality**

WQMs are Used in a Wide Range of Water Environments

- WQMs are deployed in stationary or mobile platforms or in integrated observatories
- Miniaturization, new anti-fouling mechanisms, extended battery life, submersible sensors, and solar power cells have allowed for remote deployments of WQMs in the smallest streams to the deep ocean
- Autonomous operation of WQMs has increased from a few days to as much as several months or longer thereby reducing the cost of WQM operation

Software and Hardware Innovations have Enhanced CWQ Monitoring Possibly More than Other Factors

- Data loggers have advanced from strip chart recorders to electronic digital storage devices with satellite or cellular telemetry
- Data transmission and communication systems have advanced from teletype, wire radio, and land lines to satellite telemetry, cellular, and Wi-Fi networks
- Due to advances in communication systems, WQMs can be linked together to form sensor networks

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Data Processing Software and Water Information Systems are Essential for Data Use and Reuse

- A process to review data quality, reliability, and completeness in a timely manner is essential for ensuring high-quality data
- Most organizations are using commercial spreadsheets, home-grown or consultant developed software, or commercial systems for data management
- Innovations over time in water information systems have been important for storage, retrieval, and reuse of data

Data Availability on the Internet is Resulting in Improved Scientific Understanding of Changes at the Sub-Daily Scale Leading to Better Informed Decision Making

- The timeliness of data delivery has improved from annual to near RT and RT
- Web applications provide options for:
  - Data retrieval by laptop, tablet, or smart phone
  - Geospatial customization of data retrievals
  - Data services for flexible retrieval formats and efficient data analysis

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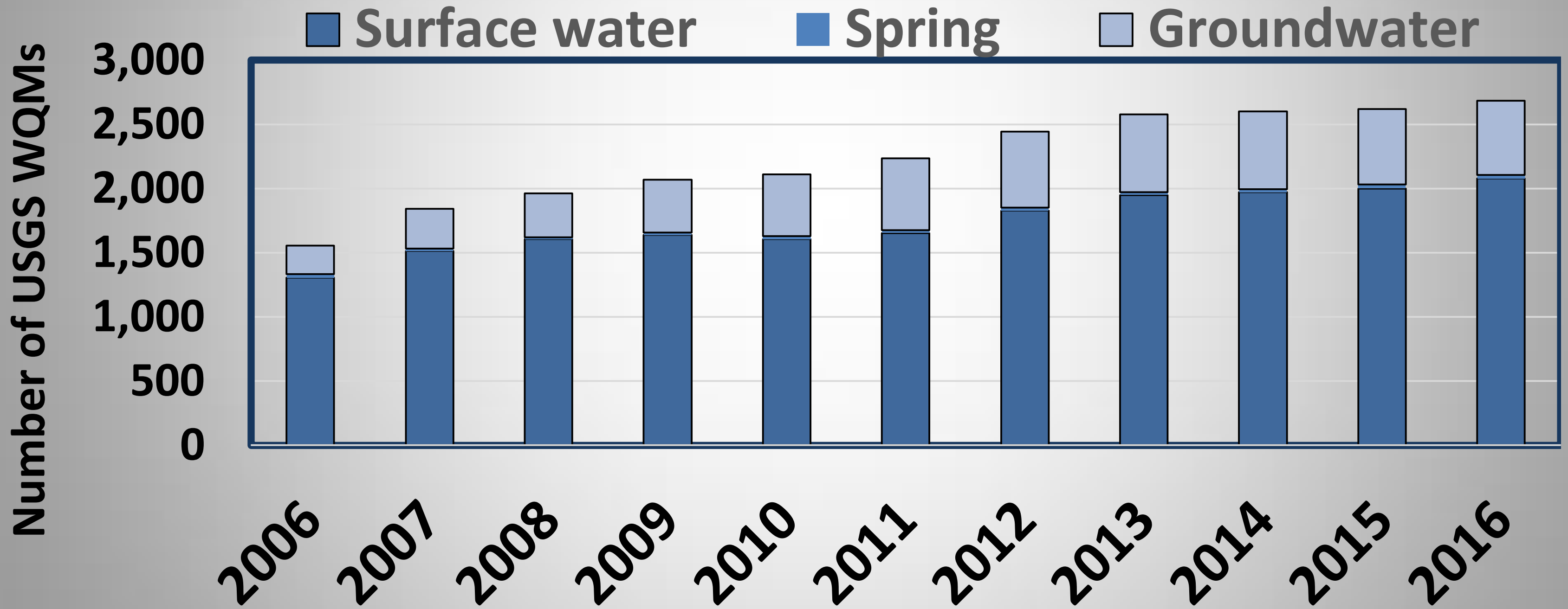
The number of WQMs has been steadily increasing
This trend is expected to continue into the 2020s

(Aquatic Informatics, 2015; Technavio, 2017; USGS, variously dated)



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Presentation based on book chapter

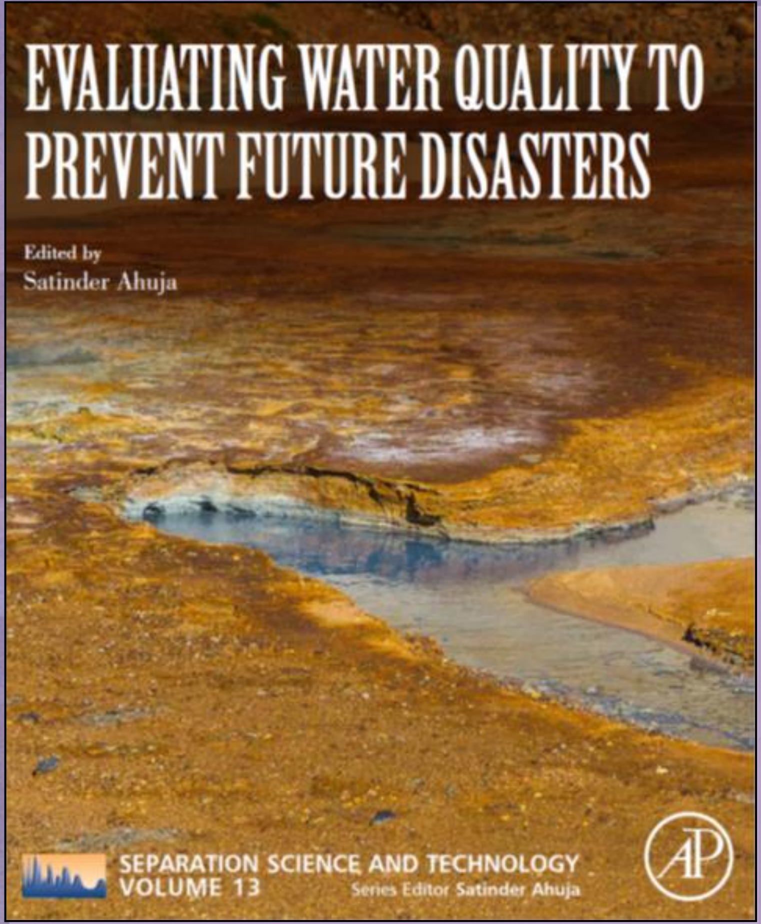
Innovations in Monitoring with Water Quality Sensors: Applications for Floods, Hurricanes and Harmful Algal Blooms

In: Evaluating Water Quality to Prevent Future Disasters

USGS

https://www.elsevier.com/books/evaluating-water-quality-to-prevent-future-disasters/ahuja/978-0-12-815730-5

Series Editor Satinder Ahuja



USGS

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