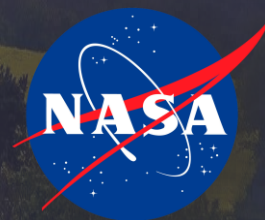
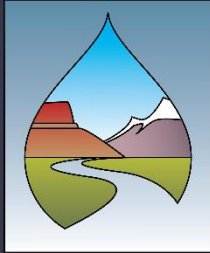

WESTERN STATE WATER RESOURCE AGENCY USE OF CLOUD COMPUTING TECHNOLOGY & PLATFORMS

October 2018



WESTERN STATES
WATER COUNCIL



WESTERN STATES
WATER COUNCIL

WESTERN STATES WATER COUNCIL

682 East Vine St., Suite 7
Murray, UT 84107
Phone: (801) 685-2555
www.westernstateswater.org

Sara G. Larsen, P.E.
Senior Program Manager
Western States Water Council
saralarsen@swc.utah.gov




Forrest Melton
Program Scientist
Western Water Applications Office
forrest.s.melton@nasa.gov

Support for this report was provided by NASA Western Water Applications Office and the Western States Water Council. WSWC wishes to express its gratitude to WWAO team members for their involvement and contributions to the survey, this report, and for graciously co-hosting the WIMS workshop at the Jet Propulsion Laboratory campus.



EXECUTIVE SUMMARY



The ability to acquire, process, maintain, and publish data and metadata related to water resource management is a critical and foundational activity that supports administration and planning by western water resource agencies. Projects, models, and the array of observations related to hydrology and watershed dynamics are rapidly increasing in complexity, spatial, and temporal scale. They are also increasing in computational requirements due to the exponential proliferation of sensor-based data, the availability of free and low-cost remote-sensing imagery, and the variety of parameters that can now be brought into the modeling process.

High Performance Computing (HPC) and cloud computing platform technologies offer solutions to the challenge of maintaining distributed or massive datasets, but there are also barriers to their adoption by state water agencies. Cloud computing platform selection, staff training needs, mismatched funding regimes, and unclear security requirements continue to be an impediment to widespread adoption. The acceptance of standardized security solutions for large federal agencies and other entities has been a pivotal development for smaller government agencies experimenting with the idea of storing data or maintaining their applications in the cloud. While a handful of states have fully embraced the notion of using cloud vendors and platforms, there is much less clarity within others.



WSWC-NASA APPROACH

There is a growing need to understand how states and local water resource agencies can effectively use cloud computing resources to sustain the new tools and capabilities offered by WSWC and NASA ASP/WWAO research teams. Both organizations have a strong interest in 1) understanding existing policies and guidelines on use of cloud computing resources; 2) identifying barriers to development or implementation of these policies; and 3) identifying best practices and case studies that could inform and accelerate adoption of cloud computing resources to enhance and sustain newly developed services and tools. Via a survey, a targeted workshop, and this summary report, WSWC and NASA's ASP/WWAO have reviewed the policies and organizational constraints within western state water agencies that may tilt the scale for, or against, cloud solutions. Several case studies of agencies' experiences with the cloud illustrate its benefits and reveal its challenges and remaining barriers.

SURVEY RESULTS

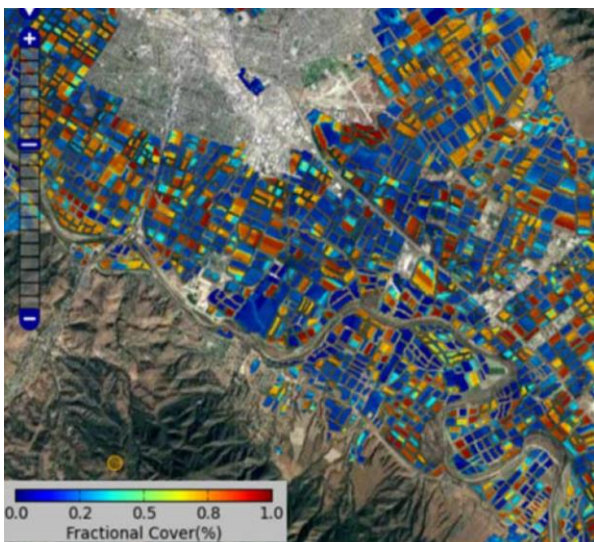
WSWC delivered a survey to the data program and IT managers of their membership to determine the extent of their reliance on centralized IT service groups, whether they currently use cloud services, why or why not, and what their experience has been with the cloud from budgetary, performance, and maintenance perspectives. All WSWC member states responded and provided a wealth of information regarding their data programs.

WATER INFORMATION MANAGEMENT SYSTEM (WIMS)

To fully understand states' capabilities and limitations, additional questions were investigated regarding cloud usage, data formats, hosting, etc. These questions helped the NASA ASP/WWAO team achieve a greater understanding of how to transition large remote-sensing projects and tools into water agency operations and decision-making. Breakout sessions amongst the workshop participants were key to understanding how management practices vary within the states, and how NASA can best support project state agency partners through ongoing communication and collaboration. The importance of early consultation, ease of data access, use of standardized formats, and inter-office engagement and training were emphasized.



WSWC AND NASA PROJECTS: FUTURE OF CLOUD COMPUTING



State water resources agencies in the West face myriad challenges when working to complete mission-critical data programs. Many are taking their first steps to include cloud computing and services in their suite of tools and strategies for water management. Some experiences with the cloud have been positive, while others have revealed barriers to greater implementation. WSWC and the NASA's ASP/WWAO team will continue to investigate what platforms and financial arrangements work well for their members and project co-sponsors. They will continue to work with project partners and co-sponsors to identify streamlined strategies to support their long-term data management needs. This may include governance bodies and partnerships that share in the benefits and costs when hosting and processing large datasets in a cloud environment.

Table of Contents

Introduction	4
Background.....	5
Investigation Methods.....	7
Survey Questions and Answers	9
Respondent Information.....	9
Use of Centralized IT Services (CIS).....	12
States Who Do Use the Cloud.....	14
States Who Do Not Use the Cloud.....	19
Benefits to Use of Cloud Platforms	21
Challenges to Further Adoption.....	25
WIMS Breakout Session Questions and Answer	27
Breakout Group #1 – Summary of Answers.....	28
Breakout Group #2 – Summary of Answers.....	29
Breakout Group #3 – Summary of Answers.....	29
Breakout Group #4 – Summary of Answers.....	30
Key Takeaway Ideas from the WIMS Workshop:	32
Future Directions	33
Strategic Considerations for NASA's ASP and WWAO Office.....	33
What Clouds are on the Horizon?	33
Endnotes	35
Appendix.....	36
State Policies Concerning Cloud Usage.....	36

Introduction

The ability to acquire, process, maintain, and publish data and metadata related to water resource management is a critical and foundational activity that supports administration and planning by western water resource agencies. Projects, models, and the array of observations related to hydrology and watershed dynamics are rapidly increasing in complexity, spatial, and temporal scale.

They are also increasing in computational requirement due to the exponential proliferation of sensor-based data, the availability of free and low-cost remote-sensing imagery, and the variety of parameters that can now be brought into the modeling process. Models may also require thousands of iterations and simulations to determine probable outcomes.

Remotely-sensed data, Light Detection and Ranging (LIDAR), Un-manned Aerial Vehicles (UAVs), interactive, real-time, and GIS datasets are particularly large, and can be unwieldy to process and manage in fixed capacity, locally maintained server environments. Likewise, data-related projects or programs that involve multiple stakeholders or contributors can be difficult to host in one location (i.e., on an agency server), while providing acceptable access, performant application hosting, and robust security for the partners. These and many other challenges inherent to local hosting and processing of data can be helped by taking advantage of advances in high-performance computational (HPC) networks and the proliferation of cloud computing technology and platforms (Green et al., 2013, Gorelick et al., 2017).

HPCs and cloud computing platform technologies offer solutions to the challenges inherent in maintaining distributed or massive datasets, but there are also impediments to their adoption by state agencies. Cloud computing platform selection, staff training needs, mismatched funding regimes, and unclear security requirements continue to be a barrier to widespread adoption by governmental agencies. More recently, improvements and standards for cloud platform security management and simple familiarity have worked to ameliorate some users' concerns over security. The acceptance of standardized security solutions for large federal agencies and other entities has been a pivotal development for smaller government agencies

experimenting with storage of data or maintaining their applications in the cloud. While a handful of states have fully embraced the notion of using cloud vendors and platforms (e.g., adopting "Cloud First" policies at a high level), there is much less clarity within others. The majority of western states have less guidance about how and when an agency should use cloud services.



In the context of this report, we consider cloud computing to encompass "shared, configurable computer system resources and higher-level services that can be rapidly provisioned with minimal management effort, often using web-based management interfaces and tools. Cloud computing relies on sharing of resources to achieve coherence and economies of scale, similar to a public utility." Resources for additional information about cloud computing, including different service models and deployment models are provided in the references for this report (Wikipedia, 2018, Ranger, 2018).

In addition to reviewing specific logistical hurdles that may exist for state water resource agencies when looking at cloud computing as a potential data management solution, this report reviews the policies and organizational underpinnings within western states that may tilt the scale for or against cloud-provided solutions. We also provide several case studies that highlight advantages for specific water agencies to cloud adoption as well as some barriers to adoption.

Background

The Western States Water Council (WSWC) is a collaborative organization comprised of members appointed by the governors of eighteen western states from Texas to North Dakota and westward to Alaska. Since its creation by a resolution of the Western Governors' Conference in 1965, the Council has striven to fulfill its chartered purpose to ensure that the West has sufficient water of suitable quality to meet present and future needs. The essential function of the Council is to foster cooperation among member states on water resource management issues and provide a forum for discussion of both the challenges and potential solutions available to the West.

WSWC's Water Data Exchange Program

In 2012, the WSWC began a cooperative effort with the Western Governors' Association (WGA), the U.S. Department of Energy (with Sandia National Laboratory as lead investigator), and the Western Federal Agency Support Team (WestFAST). The goal of the new program was to develop methods and techniques that would illuminate regional water availability over a thirty-year horizon. This analysis would then be incorporated into long-range energy transmission and generation models used by the regional energy planning entities, the Western Electric Coordinating Council (WECC) and the Electric Reliability Council of Texas (ERCOT) (Tidwell et al., 2014).

The "Energy and Water in the Western and Texas Interconnects" study highlighted the difficulty of accessing and creating comparable datasets from state water resource agencies related to water administration and water planning. To address this, and to create a framework where states could share data with others in a more streamlined and cost-effective way, the WSWC began the Water Data Exchange (WaDE) Program (Larsen and Young, 2014). WaDE targets water allocation, water supply, water use data, and related methodologies that are used by states in their planning process and basin-level analyses. Through collaboration with WestFAST, the WSWC began working with various federal agencies to develop standardized methods of accessing federal data that support state planning efforts (Blodgett et al., 2016, Larsen et al., 2016). As more sensor-based data programs are begun in state agencies, the WSWC wishes to support their incorporation into the WaDE portal. However, the

current architectural framework for WaDE presents certain challenges related to a federated but widely distributed array of "nodes."

WSWC maintains a central catalog that gives users access to state data using a common schema in a machine-readable and interoperable format (e.g., a formatted query for one state's water rights information will provide similarly formatted information when used for a different state). This workflow is accomplished by having each state implement a node where their data may be accessed via web data services. This approach has been a robust mechanism for information delivery from multiple data providers but does have some attendant drawbacks in performance, monitoring, and security. These are due to the heterogeneity of the states' data systems, computing capacity, and security protocols, and is also a function of each individual node operator's interest in updating data and maintaining the services.



Having so many nodes in geographically disparate locations also results in a difficult and slow development cycle, making it less able to incorporate user feedback and thereby improve the system's utility and use. One of several alternate solutions proposed to resolve these issues involves migrating WaDE to a centralized but still node-based, high-capacity cloud-based platform that can scale its performance to user requests as needed, provide maintenance updates, monitoring, and redundancy, while also monitoring for attacks and quantifying user

access for performance metrics. Individual node operators would still have access and control of their data, but services would be centrally located, updated, and monitored (See Figure 1).

NASA Applied Sciences Program (ASP) and Western Water Applications Office (WWAO)

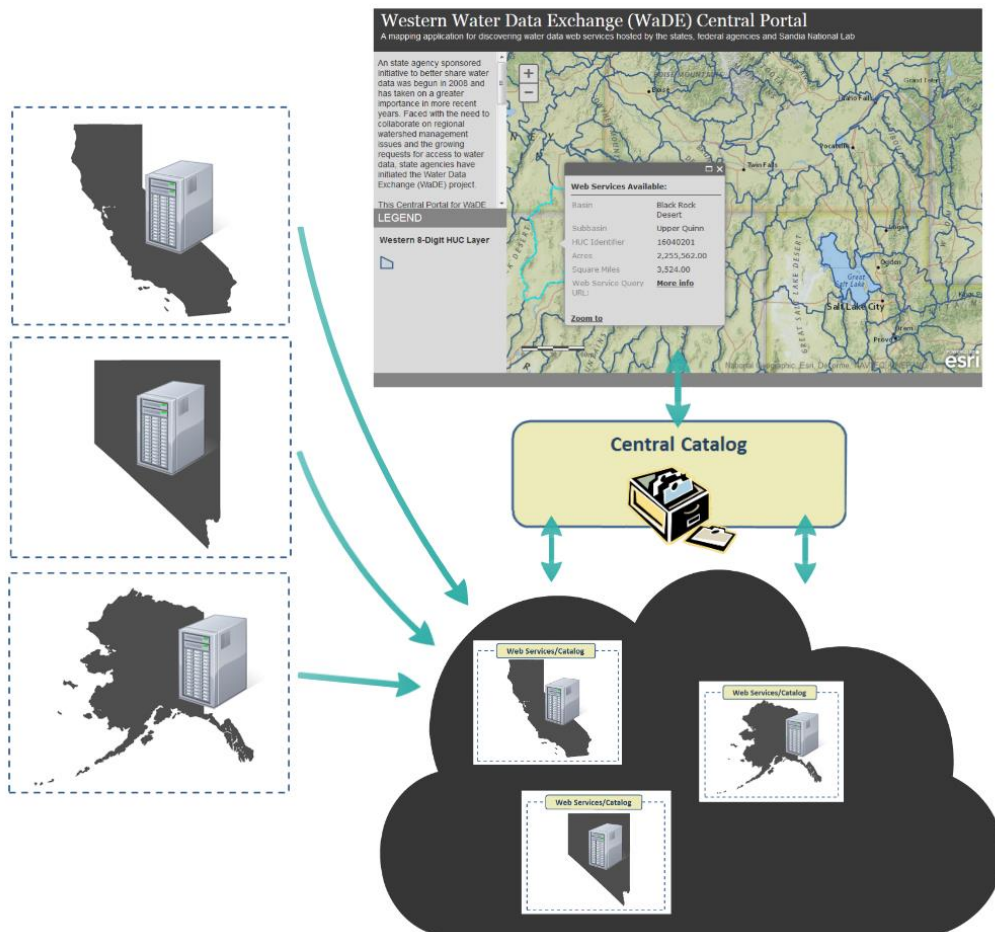
The NASA Western Water Applications Office (WWAO) is a recently created program office within the Applied Sciences Program (ASP) of NASA's Earth Science Division. The primary mission of WWAO is to accelerate the use of NASA satellite observations and associated technologies to support improvements in water management and to address key challenges identified by WWAO partners. Applied research areas for WWAO include finding new applications for existing and new remote sensing technologies, including airborne capabilities and missions on the International Space Station.

WWAO also supports applications of new technologies for data management and distribution and develops specific applications with and for non-

NASA program partners. As their mission involves characterizing and improving predictions of hydrologic phenomena to address data and information needs identified by the water resources management community, it's understandable that their partners include state water resource agencies that are charged with allocating, measuring, and monitoring surface and groundwater resources. WWAO supports a variety of projects that range from determining water availability and use, to water supply forecasting and drought monitoring, to water quality monitoring.

Growing use of cloud computing by WWAO and ASP projects

A significant task for WWAO and the ASP involves building skills and capabilities within the partner agencies to sustain applications that utilize data-intensive earth observations and models, with the eventual goal of integrating those tools into the project partner's day-to-day operations. This requires close and enduring partnerships that support advancement of a project to a point where the



Conceptual Diagram of WaDE Migration to Cloud Environment

research methods and developed tools can be successfully transitioned to the project partner, following validation of the system and demonstration of the value of the remote sensing data for the project partner. Concurrent with the trends described above, the use of the cloud by NASA-supported teams as a resource for hosting large remote sensing datasets and for high-performance computation is growing. Cloud computing offers a potentially robust, cost-effective solution for sustaining data systems and web data services that integrate data from multiple sources, provide data management and computational resources, and then publish results back to the user. Work is ongoing by multiple NASA-supported teams to leverage cloud-based resources to streamline the process of transitioning new capabilities to operational use by project partners. Key objectives of these efforts are to reduce effort and cost on the part of the partner for implementing and supporting new, jointly developed data and information systems that utilize remote sensing data to support their operational mission.

There is a growing need to understand the potential for states and local water resource agencies to effectively use cloud computing resources to sustain the new tools and capabilities offered. Both WSWC and WWAO have a strong interest in 1) understanding existing policies and guidelines on use of cloud computing resources; 2) identifying barriers to development or implementation of these policies; and 3) identify best practices and case studies that could inform and accelerate adoption of cloud computing resources to enhance and sustain newly developed services and tools.



Requirement for Data Management Plans (DMPs)

Project plans for NASA-supported projects contain data management plans (DMPs) that describe what kinds of data will be generated from the project, how that data will be supported, and what will happen to the data after the project is concluded. In the case of tool development and implementation within the operations of partner agencies, there may also be a need to plan for continued data generation, computation, and hosting after the NASA-supported project has been concluded. Other details of the DMP include how the data will be gathered, organized, documented, and a preservation strategy (e.g., on-site or remote backups in case of emergency). Specific requirements vary by institution and funder but understanding the constraints of co-investigators or project partners in terms of the support they can provide for data management at the outset of any project is essential.

Investigation Methods

The WSWC and NASA have a long history of working jointly in support of important water resource data gathering programs. As the Council has worked on the WaDE project, it has developed contacts not only with its appointees within the eighteen western states but also with their data program managers and IT staff members. This also provides the WSWC with the ability to gather IT-related information from each agency and requests related to their familiarity and use of cloud computing resources and technology. WSWC and NASA decided to leverage each other's expertise and to partner on a survey and workshop to explore these questions in tandem. The following contains a summary of their joint investigation methods.

Survey

With support from WWAO, WSWC agreed to develop a survey of approximately 10-20 questions that would be reviewed by NASA and WSWC's Water Information and Data Subcommittee (WIDS) to ensure they were complete, concise, and would achieve the desired results. The survey was hosted online, where it could be easily referenced via email. The survey results were also recorded digitally so that they could be easily summarized. The WSWC

issued the survey in the Fall of 2017 to selected council appointees of its eighteen-member states, and to the primary IT program managers that had participated in the WaDE program.

Follow-up

The respondents were given ample time (several months) to ask questions and provide answers, complete with follow-up interviews with individual state staff where clarification was needed. Reminders to complete the survey were issued to encourage full participation. Within the timeframe allotted, all WSWC members responded to the survey.

Water Information Management System (WIMS) Workshop

To fully understand states' capabilities and current challenges, additional questions related to their use of the cloud were added to the investigation. The WSWC and NASA also desired to engage in a conversation with agency staff and explore the topic

of cloud usage more fully. It was proposed that the WSWC and WWAO co-host a workshop at the NASA Jet Propulsion Lab (JPL) to engage directly with WSWC members, to explore the status of cloud usage, and to introduce state IT program staff to the programs and tools being developed by WWAO and NASA ASP.

The WSWC initiated a Water Information Management System (WIMS) workshop, hosted by WWAO and held at NASA JPL in Pasadena, CA. Held on January 16-18, 2018, the WIMS workshop provided a collaborative forum to discuss these and other state agency data management topics. There were 36 presenters, many of whom were representatives from states agencies, and approximately 75 attendees on site and attending remotely via webinar. The additional question and answer sessions related to use of the cloud and the NASA research team are discussed in greater detail in the WIMS Breakout Session Questions and Answers section.



WIMS Workshop Attendees Discuss NASA-WWAO projects on the Jet Propulsion Laboratory (JPL) Plaza

Survey Questions and Answers

Respondent Information

All 18 states that comprise the western U.S. and WSWC membership responded to the survey. In two states, two responses were received, one from an additional planning agency, and the other from a water quality/water rights administration agency. The answers from the additional agencies were similar enough to be combined into one response from the state. Thus, the following survey information is for 18 states. The positions held by the respondents ranged from Chief Information Officer (CIO) to Information Services Managers to Deputy Director – generally in mid-to-upper level management of the agency.



When asked about the agency's mission, most respondents indicated that they were responsible for water rights administration, state water planning, and some were also responsible for providing oversight to water quality within the state. The survey was comprised of three parts: the state's use of centralized IT services (CIS), whether the state used any cloud platform or vendor for any services, and for those that did, what were the benefits. For states that reported not using the cloud, the survey requested information as to why and whether their agency was reviewing cloud platforms as an option for hosting in the future.

Importance of Centralized IT Services (CIS) to Application Deployment

States generally subscribe to one of two approaches when working with and providing IT services: that of either centralized services with one agency or body governing most or all IT-related procurements and activities; or decentralized, characterized by state

agencies managing their own hardware and IT activities independently. Reasons for consolidation vary by state but generally include the avoidance of duplication of work, procurement efficiencies, consolidation of IT skills and staff members in one department, greater adherence to industry standards, etc. CIS service groups may also better monitor performance of a wide variety of services and security across a larger organizational platform, may provide help-desk services that are more efficient and/or more responsive, and hopefully at a reduced overall cost to the state. With the many public-facing applications deployed by decentralized agencies and the increased threat from hacking, spoofing, and phishing, there is a strong argument to be made for implementing stronger and more consistent security protocols that can protect from data loss or intrusion.

Conversely, there can be significant negative outcomes from consolidation also. What were once small, specialized, and agile IT staff groups within agencies may be pulled into the larger body of the consolidated department and find that their specialties are not as useful or as good a fit. The initial transition of IT staff out of their home organization (even if they remain onsite) is often difficult and involves integration into a new management structure. Agencies may find that the CIS department is less responsive or not as tightly integrated with their specific needs and goals. Agencies may also find that, as opposed to purchasing a server, individual licenses, and having an "on premises" server/application at a known flat cost, consolidation may include paying for "virtual" hosting capacity, sometimes located off-site. This can have significant performance impacts on the agency's legacy applications. They may not even be supported by the new department. Also, the agency may find themselves paying a monthly or annual hosting fee that fluctuates from month to month or



year to year, thus creating another variable of uncertainty in agency budgets.

Installation of Applications with or without CIS Assistance

The status of IT services for a given water resource agency impacts the ease or difficulty with which they may install and maintain new applications. What would have involved only the home agency in the past, now involves two, one of which is charged with security and efficiency as their highest obligation. At least initially, the stance toward any new prototypes or piloted applications may be negative. The CIS department staff assigned to the agency may change with each project (as with a “Help Desk” ticket system).



Agencies may also find that the time needed to adjust their applications using the CIS department is time-consuming and cumbersome. An example would be a staff member asking for a permission change in a database – a simple thing to adjust, but which may take much longer via a help desk system. State agencies have tried to manage such issues by instituting performance metrics based on efficient closeout of help desk system “tickets”, but some tasks remain more easily accomplished by the original database or application designer, or simply by someone on location who has access to the server. Agencies have also tried to address disconnected staff and slow response times by designating a CIS liaison – a person who is familiar with agency staff members and their technical issues and questions and can advocate on the agency’s behalf with the larger CIS group if needed.

In the survey, we found that many states, after some trial and error, have settled on a hybrid approach to IT

services where the agency can support applications directly, but also works with a CIS agency for larger projects or when specialty services are required. For practical implementation purposes, this suggests that new projects may be deployed or piloted from the water resources agency relatively quickly. However, there may also be restrictive barriers to deployment that require CIS involvement. If the CIS is required, delays may be introduced for the necessary justification and/or testing to approve the new approach or application. The costs for installation and hosting may also need to be evaluated by a second party.

Currently, the best strategy for NASA WWAQ, ASP, and WSWC, when looking to deploy new tools or apps with a state agency, is to determine at the outset of a project what the extent of the state agency’s capabilities are for setting up and hosting themselves. If CIS is required, WSWC and NASA should involve them in the project as soon as possible to understand the CIS department’s limitations, standards, supported capabilities, etc. The project sponsors may also need to plan for a longer timeframe for transitioning the tools to operations. The predictability of costs (e.g., a one-time purchase of a server vs. fluctuating hosting costs) is also important when evaluating new data program costs over the longer horizon.

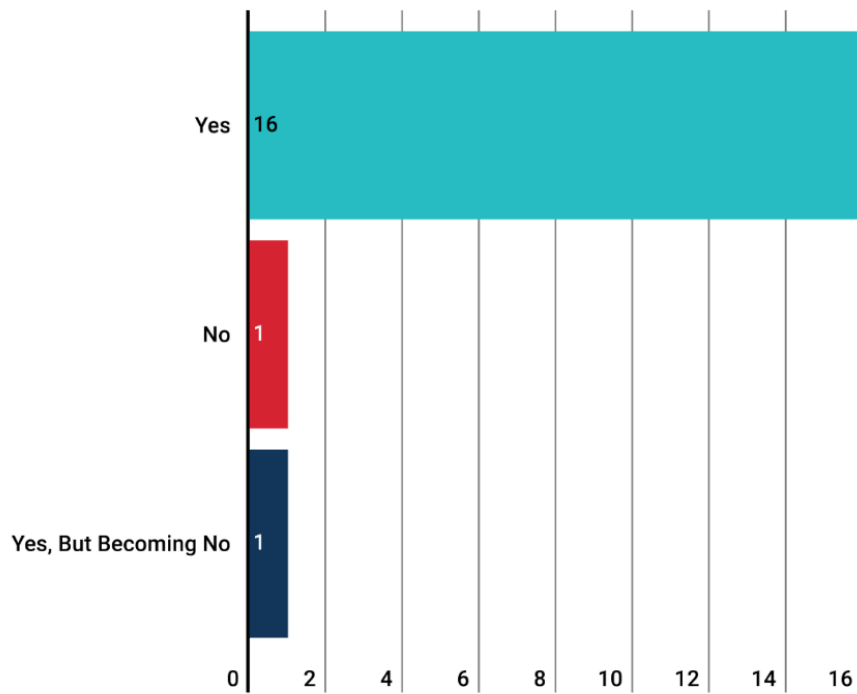
Loss of Expertise and Interaction with CIS Services

In the past, a typical water resource agency was comprised of specialized program managers and staff (e.g., engineers, hydrologists, water rights administrators), and technical support staff that assisted with their work (e.g., GIS analysts, database administrators). This, in turn, enabled a conversation, enabling technical staff to learn about the unique needs of water resource engineering and programs, and conversely for program staff to learn about most recent technical innovations. In a consolidated framework with less direct interaction between the two, each runs the risk of losing the benefits of those conversations, i.e., engineers and hydrologists no longer hearing about technical advances in GIS, cloud platforms and services, remote-sensing innovations, etc., and vice versa. This is of great importance to

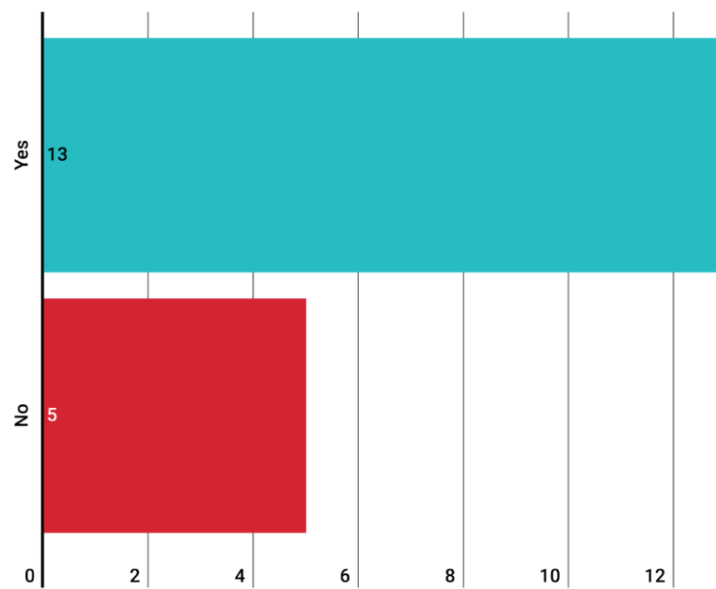
NASA's ASP and WWAO. As NASA has engaged with stakeholders on their advancements, there have been instances of the stakeholder being unaware of improvements and advances made in relevant science and applications. Likewise, as WSWC has sought to install the WaDE applications with its member states, the agency staff have expressed concerns about the dissolution of tightly coupled IT services within their agency.

Use of Centralized IT Services (CIS)

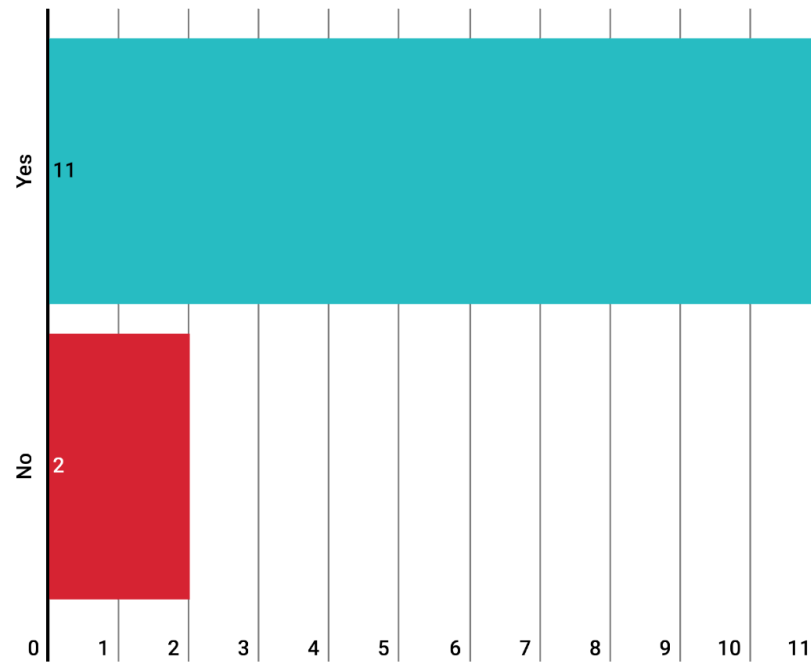
CIS Question #1: Do you host your own applications, or store your own data within servers on-site (machines that are physically accessible to you)?



CIS Question #2: Do you host/store applications or data with the assistance of a centralized IT services (CIS) department?



CIS Question #3: If you do work with a CIS department, do you have a dedicated liaison with whom you typically engage and request assistance?



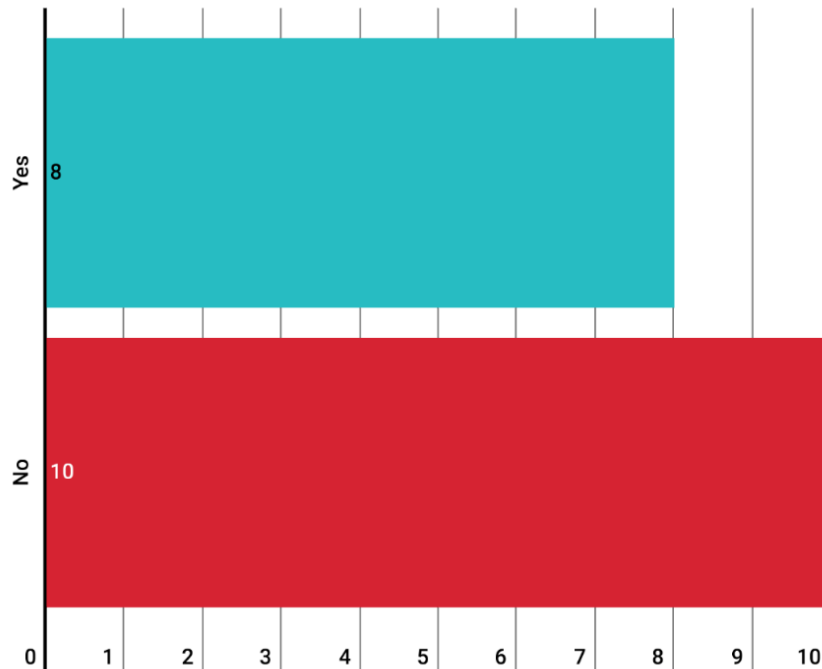
CIS Question #4: How do you procure your IT services?

Response: Most states (11 out of 13) that have a CIS department answered that they procure those services through their dedicated liaison and/or through the agency's "Help Desk" ticket system.

States Who Do Use the Cloud

Most agencies reported having policies concerning use of the cloud, but some are quick to point out that these policies are evolving quickly. Also, they run the full spectrum of use, i.e., states may be required to consider use of the cloud first before procuring “on-prem” hardware, and states may be prohibited from using the cloud.

Cloud Use Question #1: Whether administered by a central IT department or your agency, are any of your water management applications, modeling, or data stored in, processed in, or hosted by a "cloud" vendor (e.g. Amazon Web Services, Google, RedHat, Socrata, etc.)?



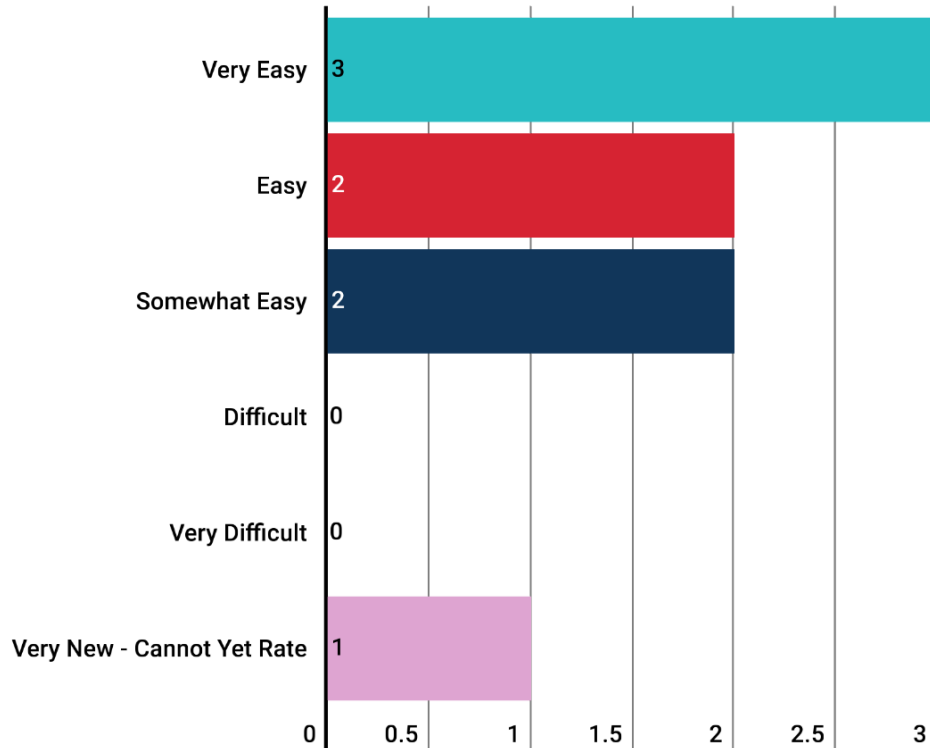
Cloud Use Question #2: Who are your cloud providers?

Response: Amazon Web Services (AWS) (4), Northwest Knowledge, Caspio, GoDaddy, Google, Microsoft's Azure.

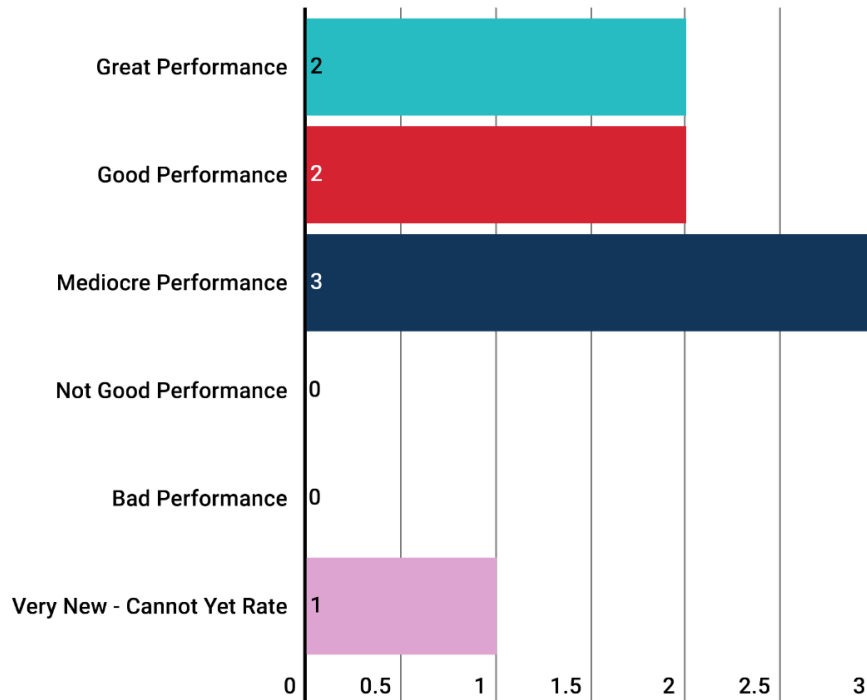
Cloud Use Question #3: Why did your agency opt to go with a cloud vendor? States who are currently using the cloud report the following reasons for opting for cloud-hosted solutions:

- Much less expensive [than hosting locally], scalable
- Hosting larger imagery datasets with other partner agencies
- Ease and speed of web service installation and piloting (2)
- Useful as an interim data-providing solution
- Security and associated costs
- Required to use the cloud – the state has a “cloud first” initiative
- Use is tied to a software purchase

Cloud Use Question #4: How would you rate the performance of the cloud vendor regarding ease of maintenance by you or your staff? In other words, how easy is it for you to maintain, update, interact with your apps/models/data on the cloud?



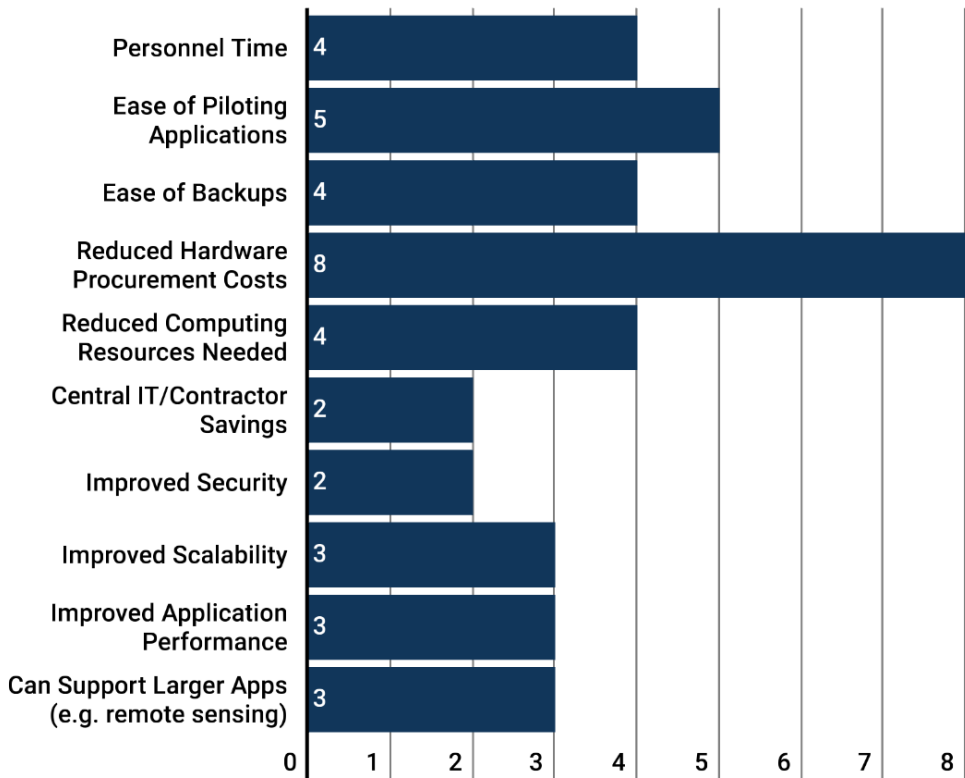
Cloud Use Question #5: Are your data customers and users able to get requested information quickly and reliably with the cloud vendor-supported services, with minimal or no outages or lag time?



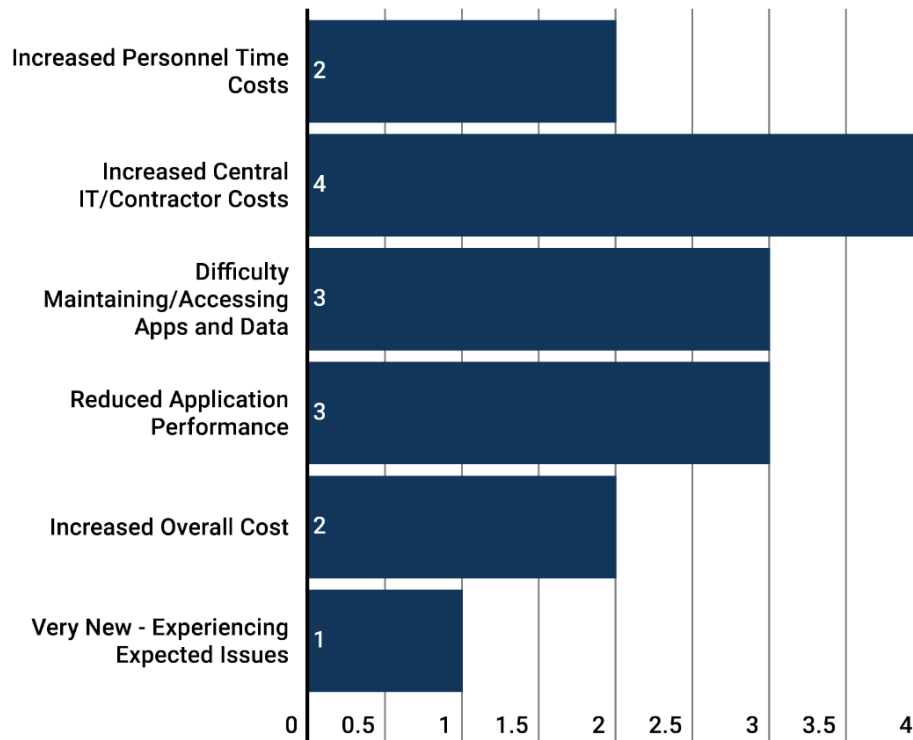
Cloud Use Question #6: Please provide any additional comments concerning performance or vendor support:

- “services have been quite stable”
- “more reliable than our internal network”
- “you get what you pay for”
- “license and contract ending... not renewing”
- “very new, cannot yet rate” (2)

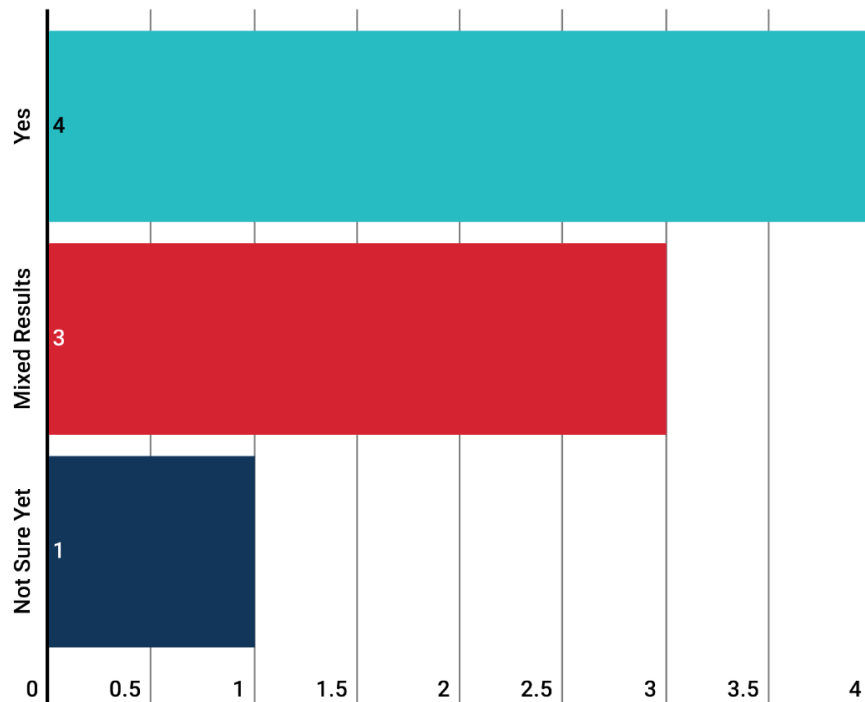
Cloud Use Question #7: What are the benefits that your agency has seen from using a cloud vendor to support your apps/models/data storage. Select any features from the list that apply.



Cloud Use Question #8: What difficulties have resulted or what barriers/costs have you encountered using a cloud vendor to support your apps/models/data storage?



Cloud Use Question #9: Overall, has using the cloud worked for your agency?



Cloud Use Question #10: Do you think your use of cloud computing will increase in the future?

Response: 67% of the respondents who currently use a cloud platform indicated that they thought their use would increase in the future.

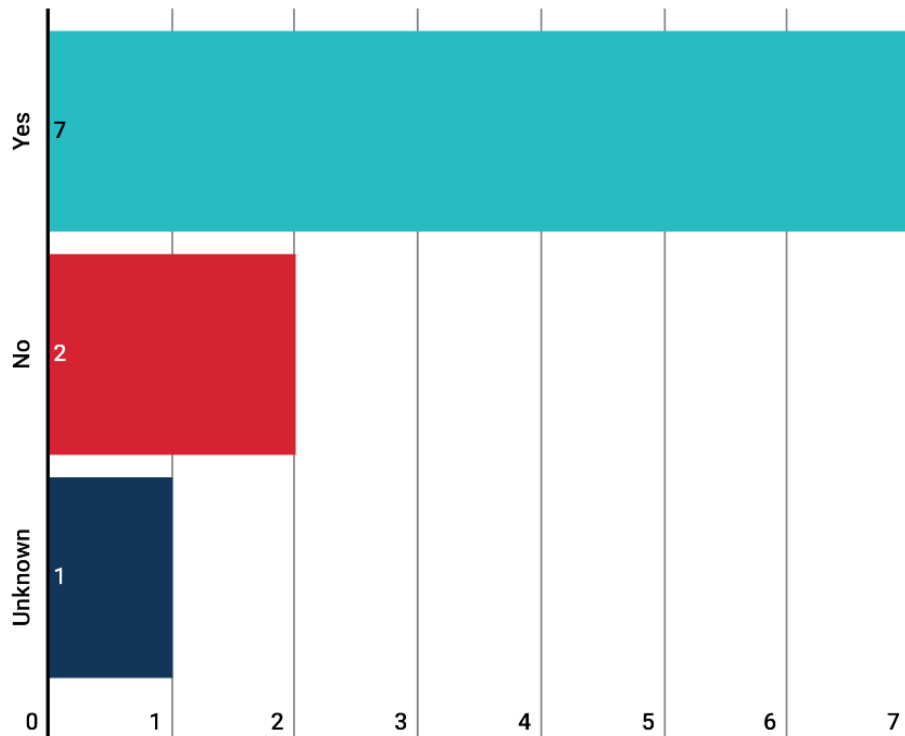
Cloud Use Question #11: Is your cloud vendor fee based on user access, or a flat rate?

Response: Six out of the eight respondents who currently use a cloud platform indicated that their vendor fees were based on a flat rate (monthly or annual amounts). The two states who had user-based fee structures indicated that the fluctuating billing was not an issue for their office.

States Who Do Not Use the Cloud

Some state agencies have investigated use of cloud platforms for supporting their operations but have made the decision not to adopt those solutions. This portion of the survey seeks to understand the variables that contributed to their opting not to use a cloud solution.

Cloud Investigation Question #1: Has your agency looked at hosting any of your water management

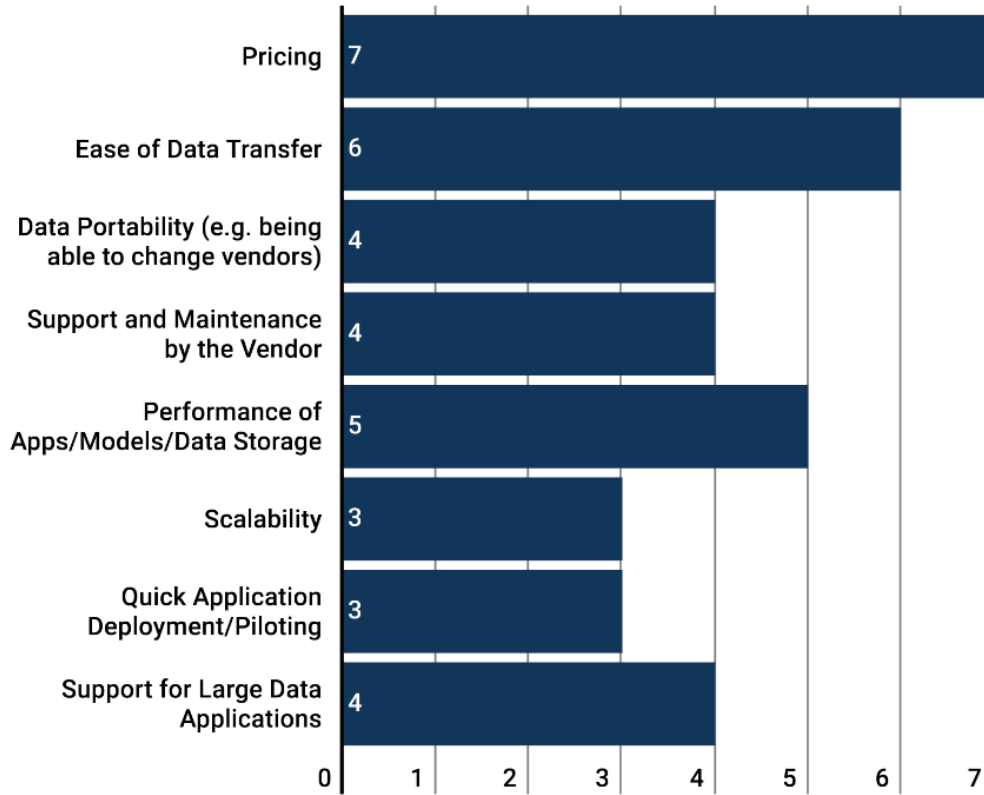


applications/models/data with a cloud vendor? Or investigating the possibility with the assistance of your central IT agency?

Cloud Investigation Question #2: If yes, are you still in the review process?

Response: 5 out of the 7 investigating states were still in the midst of their review.

Cloud Investigation Question #3: If you are still reviewing, what issues are you most concerned about?



The two states not reviewing cloud platforms provided some explanation of their status. One indicated that their current IT infrastructure was sufficient to meet their current and projected needs and that cloud usage was prohibited in the state. The other remaining state said that investigations had been concluded and a statewide vendor was selected for usage by all state agencies; however, they did not intend to use the vendor.

Benefits to Use of Cloud Platforms

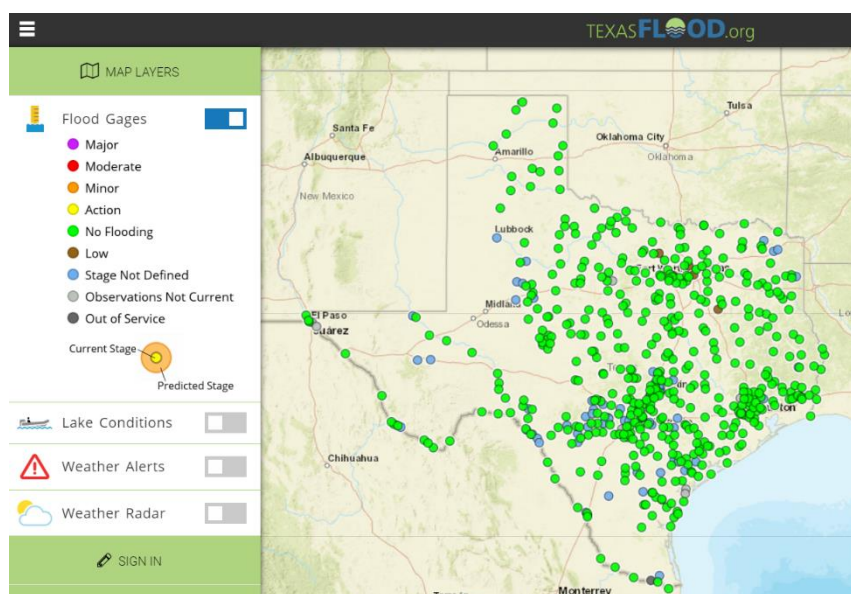
There are several inferences that can be made from the general results of the survey investigation. State water resource agencies that have an interest and the capability for rapid prototyping and testing of applications are well situated to take advantage of the flexibility provided by cloud computing platforms. Similarly, if the state needs a platform for supporting relatively small applications (needing good performance but with less storage and processing memory required). If a state has the capability to utilize data porting technologies that make it easier to move data and applications between cloud vendors, they are better situated to take advantage of cloud options without feeling locked into any one vendor. If an agency has a limited footprint for more servers and other infrastructure, the cloud is a good alternative to hosting locally.

Cloud platforms also work well for water resource agencies that are interested in larger applications and data storage, such as are needed for large satellite or other imagery datasets and sensor-based observations. Clouds are especially attractive if the state has the option of pooling resources with other partners to co-host the data at a discount. For some states, hosting on cloud platforms may be competitively priced when compared to the state's CIS pricing. Provided it is permissible to either bypass CIS or work through the CIS department to procure the cloud services, the cloud may be less expensive or offer more attributes (e.g., scalability, better performance or support) to outweigh the increased cost. It may be that the state is simply required to utilize cloud services wherever possible before considering other options (one survey state has this requirement), and thus its use becomes much more likely.

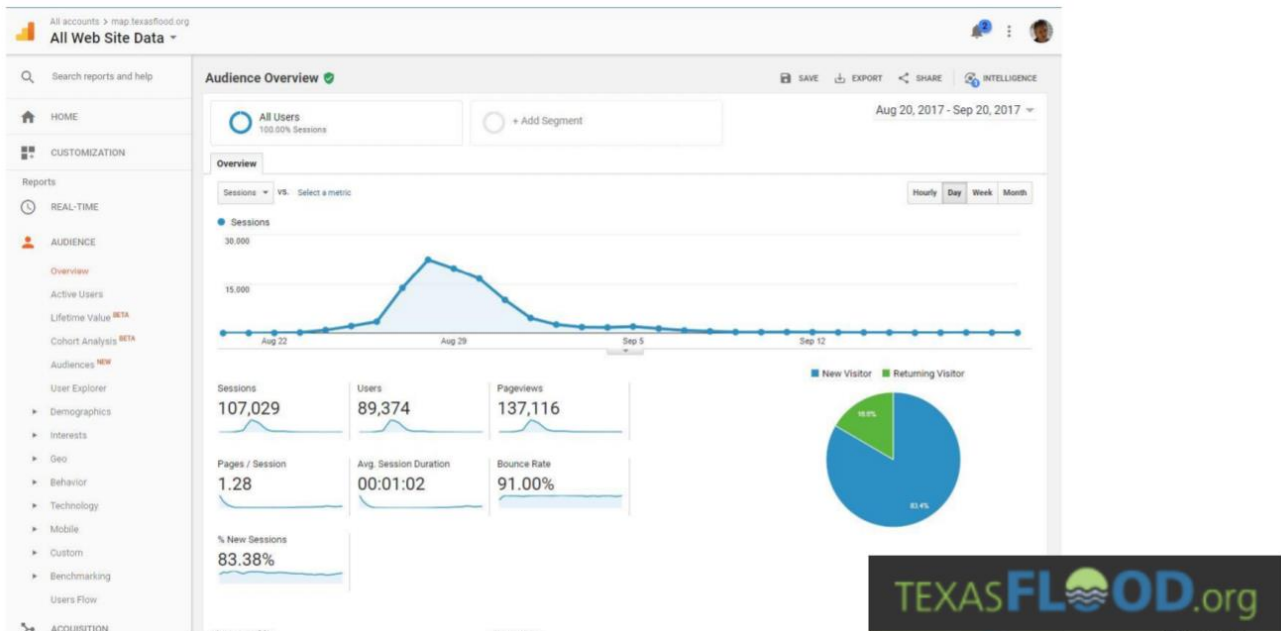
Case Study: Texas Water Development Board – Flood Mapping and Water Planning Data

In 2005, the Texas legislature passed HB 1516, a bill to consolidate all state IT services into statewide technology centers. The intent was to reduce statewide costs for IT services, modernize aging IT infrastructure, and increase overall security and disaster recovery capabilities. Due to challenges with the initial transition, the Texas Water Development Board was approved to participate in the Texas Pilot Cloud Program. After building out a cloud environment to host its existing applications (35-40 servers at a cost of about \$30,000/month), the agency decided to review the costs and benefits of using a cloud service provider. The TWDB found that – though the State's data center provided significant security advantages – the cloud vendor offered numerous features that were attractive to the agency, such as scalability for user traffic spikes, on-demand pricing, increased resiliency and redundancy, real-time application performance evaluation, and local control and operation of the application. The cloud offering also proved to be more cost-effective for the agency. The statewide technology center recently added a hybrid cloud services offering to its program, which the agency plans to participate in moving forward.

An example of how the TWDB currently uses cloud services can be seen in its Texas Flood Viewer, which is based on data that is cached and then shared using Amazon Web Services. Rivers and



Texas Flood Mapper Application



Hurricane Harvey Google Analytics Data for Texas Flood Mapper

streams that have gauges are “scraped” on an ongoing basis from trusted USGS and NOAA websites to present a user-friendly map of rivers at their near-realtime flow. The user can also opt to see lake conditions, weather alerts, and radar information superimposed on the map. During Hurricane Harvey (August 17, 2017 – September 2, 2017), the TWDB Flood Mapper website received a significant uptick in user traffic, eventually serving over 89,000 users over the span of the storm.

The majority of these users were new to the site. The AWS platform hosted the data in redundant sites so that users were able to view the cached copy that was nearest to their current location, and the application automatically scaled up to meet the new demand. When reviewing the storm and its impact on their data services, TWDB stressed that the value of providing flood-related data during normal weather conditions is very low, but the value increases substantially during a hurricane or other flooding event, as users need to find information about their local watershed from a trusted source.

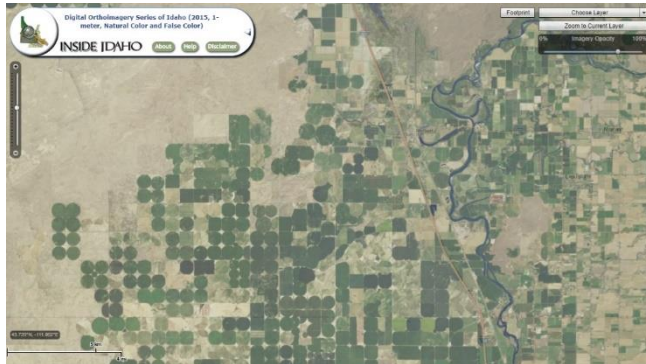
Case Study: California’s State Water Resources Control Board – “Cloud First” Policy

In 2014, the California Office of Technology Services (OTech) adopted an alternative framework for new IT projects called the “Cloud First” policy. This requests that OTech and all California state agencies shift toward primarily cloud computing services, with vendors provided by OTech given priority over other commercially available options. The new policy is expected to accelerate the adoption of the cloud in California, but any new IT projects must also comply with a long list of requirements. Besides being required to prioritize OTech supported cloud vendors, agencies must classify their data managed within the cloud, ensure compliance with all state-mandated security provisions (including encryption where needed) for their data classification, ensure that the physical location of the data facility is within the continental U.S., maintain an exit strategy for the project and vendor, and maintain an incident response plan in case of a data breach or loss.

California’s State Water Resources Control Board (SWRCB) is in the early adoption stage of using the cloud. It is their strategic goal to move their applications to the cloud over time. They operate in a highly virtualized environment already and are working to reduce their physical footprint. (An unusual reported benefit of utilizing the cloud may be a reduction in needed office space.) SWRCB has approached their next substantial IT project with the cloud in mind – a pilot cannabis registration and permitting database

and website – using a combination of Amazon Web Services and Microsoft’s Azure. The performance, stability, and costs of the new platforms are still being evaluated.

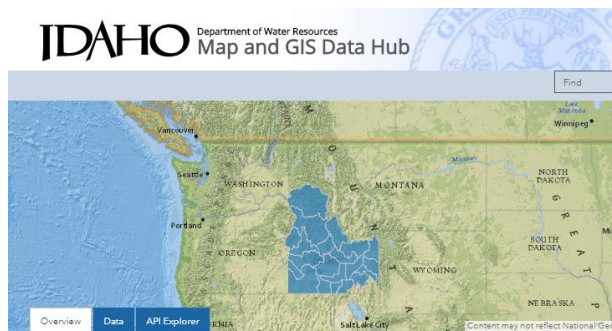
Case Study: Idaho Department of Water Resources – Sharing the Costs for Imagery and GIS Data



Idaho Department of Water Resources (IDWR) uses the National Agriculture Imagery Program (NAIP) imagery extensively within its office to map field boundaries and quantify agricultural water use. NAIP imagery datasets are offered by the U.S. Department of Agriculture (USDA) at a cost, and the datasets are quite large. Early in the program, IDWR collaborated with several other partners under the Idaho Imagery Technical Working Group (TWG), to coordinate the initial purchase of four-band multispectral imagery for the entire state. The TWG arranged for the data

to be hosted and made accessible to the public using the Northwest Knowledge Network (NKN), a “cloud” provider partnership between Idaho’s universities and Idaho National Lab. The NKN services include data storage, the development and hosting of applications, databases, websites, and virtual machines, and consulting. IDWR and the TWG partners continue to support NAIP and the provision of other geospatial information through the NKN, and Inside Idaho, the Idaho Geospatial Clearinghouse at the University of

Idaho.



Snake River Basin Adjudication Reporting Areas

Custom License 5/10/2018 Spatial Dataset 21 Rows

Administrative areas for the reporting of domestic and water right claims in the Snake River Basin Adjudication by the Director of the Department of Water Resources.

Attributes

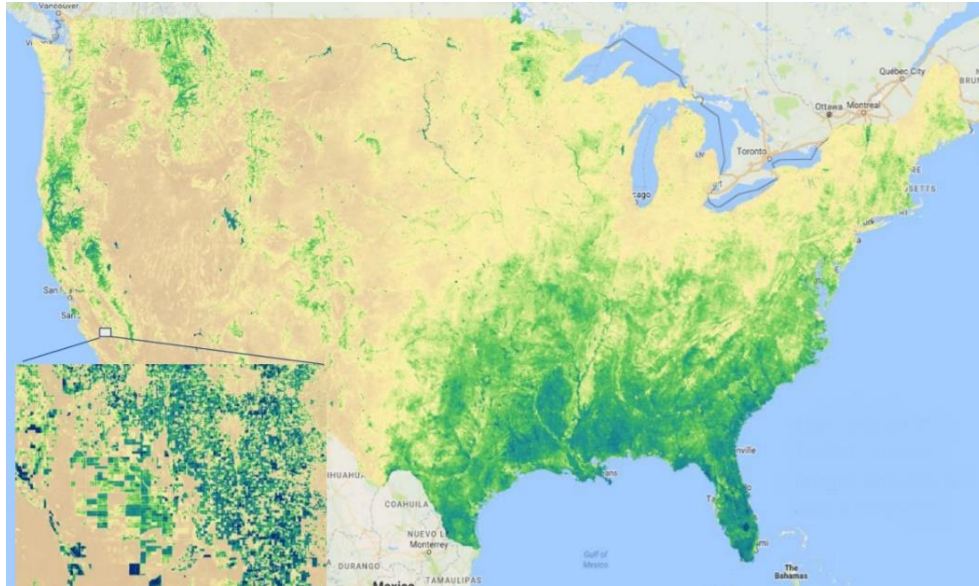
Chart Map Visualization

ACRES	REPORTING AREA	USES	SHOW MORE
Number	Number	Text	2 Attributes

IDWR also takes advantage of their state’s enterprise license with ESRI for sharing data using ArcGIS online (AGOL) – ESRI’s GIS cloud solution based on Amazon Web Services. AGOL’s Open Data platform allows users access to an organization’s data in a variety of formats using a streamlined and easily accessible interface. The costs related to AGOL are based on “credits” that are used for storage of the data, geoprocessing services, and user access to the information. The unpredictability of the purchase of AGOL “credits” has thus far not been a deterrent for IDWR because they are able to leverage their IDWR ArcGIS server for geoprocessing services that could consume a large amount of credits within AGOL.

Case Study: The OpenET Project

Remotely-sensed information is becoming increasingly important to water resources management, including administration of water rights, water planning, interstate compacts, court decrees, and administration of tribal water rights. Particularly useful are capabilities that utilize remote sensing to map evapotranspiration (ET), leading to improved measurements of consumptive surface and groundwater use, data that can be used to support water trading programs, and more efficient irrigation and water conservation within the agricultural sector. As irrigation of agricultural crops is the largest human use of water in the West, tools that provide insight into its quantification are invaluable to planners, farmers, and administrators alike (Willardson, 2014).



The OpenET Project is a community-focused open source effort to quantify water used by agriculture in western states (Huntington et al, 2017). The project partners are comprised of teams at NASA, the Desert Research Institute (DRI), the Environmental Defense Fund (EDF), Google, USDA, USGS, multiple universities and many participating state water resource agencies as partners and eventual beneficiaries of the project. The project is leveraging a multi-petabyte archive of satellite and weather data housed on Google's Earth Engine platform, which provides a standardized interface for performing operations on the data using Google's cloud architecture.

The project is applying multiple well-established evapotranspiration (ET) algorithms to the grids and combining the satellite-derived data with ground-based weather station data to arrive at estimates of consumptive use at the field scale. The project is building a web-based platform to provide the data to end users across the U.S. and giving the user the ability to request, visualize and download data for locations and time periods of interest. Use of Google Earth Engine and Google's cloud is an essential component of the project and provides access to Landsat, MODIS, VIIRS, GOES, and Sentinel-2 data. Earth Engine will also be used to provide a common platform for processing the imagery using several accepted methodologies (METRIC, DisALEXI, SEBAL, SSEBop, SIMS, etc.) to derive ET products over a much larger timeframe and spatial extent than has ever been attempted in the past. Case study locations span several basins and involve many partners from the states' water resource agencies.

The first successful test of this approach by the research team resulted in nationwide, field-level ET maps using the Google Earth Engine platform – a feat involving 16,000 Landsat “scenes” processed over a 48-hour period. The researchers are working to establish a longer record for actual ET estimates over large areas for use by partners and the public.

As the number of states that are engaging with the project is large, and they will be the primary beneficiaries of the project after its initial implementation, it may be proposed that a consortium of partners fund the continued operation of its implementation on either Google Earth Engine and/or another remote-sensing optimized platform. It is important for the research team members to address transition-related questions (e.g., where data be hosted, how much will it cost to process and distribute, who will pay for it) as projects are initially developed.

Challenges to Further Adoption

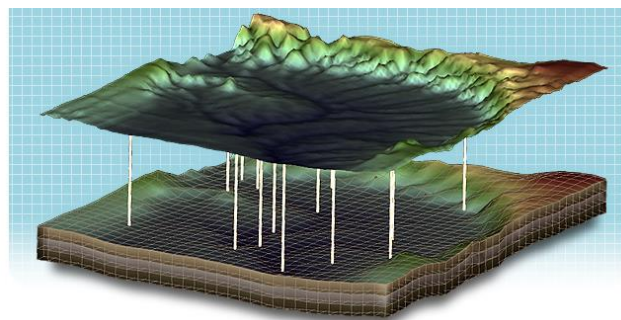
There are several inferences that can be made from the survey about its challenges as well. Generally, the results of the survey indicate that there are some reservations among state water agency staff about cloud computing and relocation of datasets. For these agencies, the cloud may not be a good option if they are looking for more robust or larger applications than what would be used for rapid prototyping if the cost is considerably higher than local IT services and support. State agencies that have hardware that is sufficient and projected to support the needs of the department are unlikely to consider cloud computing platforms.

If the time needed to train staff members on use of the cloud, or likewise if the time required to both initially move data to a cloud platform and retrieve it are too great, the cloud is not a good option. Moving and configuring data and applications to a cloud vendor requires substantial time and cost, and not a small amount of risk if the agency is not certain that the vendor can provide for their needs. Some agencies have fixed budgets that make the fluctuations of cloud pricing less attractive. One survey respondent indicated that their CIS department charged their state agencies not by storage and hosting hours, but by bandwidth consumption on state networks. Transferring data back and forth from a cloud would be prohibitively expensive under this CIS cost arrangement.

Case Study: Idaho Department of Water Resources – Groundwater Model Calibration Using the Cloud

During 2017, IDWR evaluated the use of cloud computing resources for calibration of groundwater flow for the Eastern Snake Plain Aquifer Model (ESPAM) and the Wood River Valley Model (WRV). These model calibrations, of all IDWR's routine business tasks, required the greatest dedication of computing power. The model calibration was performed using the least-squares inverse modeling Parameter Estimation (PEST) software and required a very large number of model runs for accurate results. IDWR had two multi-core computers dedicated to this task (affectionately termed the "PEST nest") but found that additional computing resources were needed to enable the use of both models.

Cloud computing using the PEST.cloud interface was tested as an alternative to purchasing additional on-site hardware. The advantage of PEST.cloud was the ability to rent a large number of computing nodes



without having to buy or maintain any new hardware.

The primary disadvantage was the cost of renting the cloud computing services. IDWR hydrology staff performed 10 calibration runs on PEST.cloud over a period of one month for a cost of approximately \$1,600. The cost of purchasing two additional multi-core computers is approximately \$13,000. The two multi-core computers would be comparable and have similar computational capacity to PEST.cloud, but over the longer horizon would cost considerably less. Aside from the cost, two other disadvantages to PEST.cloud were noted: 1) PEST.cloud uses the version of the software that did not support the predictive analysis mode that IDWR needs to perform uncertainty analysis for ESPAM. 2) PEST.cloud only facilitated the use of pre- and post-processing programs that can be compiled as executable files. IDWR's WRV model used a pre-processor written in R (a popular language and tool for scripting statistical programs), and significant effort would be needed to modify the pre-processor so that it could work for the cloud version. Ultimately, the hydrology section opted to purchase the multi-core computer instead of using cloud services and were able to get the R program to run as an executable.

Case Study: North Dakota State Water Commission – Data Management Infrastructure Budget Uncertainty

The North Dakota State Water Commission (NDSWC) has made a significant investment in data provisioning for its internal customers and to the public. During an evaluation of their IT program's costs and services, it

was found that 90% of funding was for data acquisition, and 5% were spent on application development and infrastructure (e.g. servers, software, maintenance, etc.). However, NDSWC has found that these technology costs have increased when funding is required to support long-term projects. Further, the technology costs associated with the project often dictated the success and failure of the data management solution, even though it represented a minor component of the overall cost of the data program.

NDSWC needed to immediately address this concern when their budget was significantly reduced amid implementation of a new infrastructure program. The agency was compelled to make drastic modifications to their data management plan that involved dropping

all vendor-based data management tools. The agency then reconfigured their operations with an entirely open source approach, utilizing predominantly PostgreSQL, PostGIS, MapServer, QGIS, GDAL, and OSGeo to continue their data programs. Since that initial stressful period of adjustment, the NDSWC IT program office has been able to reduce their total data management infrastructure costs to simple hardware needs, at a savings of more than \$200,000 annually. Their infrastructure expenses are still subject to the same budget variations, but the agency has the ability to extend the life of local hardware infrastructure to accommodate budget fluctuations and shortfalls. With the cloud's pricing fluctuations and given their experience with disruptive budget changes, the NDSWC has not reviewed cloud services as a possible hosting solution.

WIMS Breakout Session Questions and Answer

During the Water Information Management System (WIMS) workshop co-hosted by WSWC and NASA WWAQ, small breakout sessions were formed to further investigate states' needs regarding NASA project transition steps, states' use of the cloud, preferences regarding data formats, and support for projects once they were in operation. The questions each group addressed included the following:

- 1) **What advice would you give to NASA at the outset of a new project to increase the likelihood of successful transition to operations?**
 - a. Are there key data standards, metadata standards or data formats that should be considered for a new project?
 - b. For a new capability that is data intensive but leverages commercial cloud-based resources, how should project's partner with a state agency to plan for long-term financial support?
 - c. What other best practices should NASA consider in partnering with state agencies to develop new capabilities?
 - d. What should be avoided?
- 2) **What are currently the most important water-related data gaps that you or your agency routinely encounter?**
 - a. Are there particular requirements that applied research teams should be aware of in working to address these data gaps (e.g., minimum geographic scope, spatial resolution, temporal resolution/frequency, data latency, the minimum duration of the historical data record, data accuracy)?
 - b. Are there related ground-based datasets that the applied research teams should be aware of?
- 3) **Has your agency recently had to integrate any new data sources, observations, data services or data management tools into your operations? If so:**
 - a. Did you utilize a cloud-based resource to implement this new capability?
 - b. What worked well?
 - c. What were the challenges?
 - d. Were there any key lessons learned?
- 4) **What tools does your agency currently use to manage its largest geospatial datasets?**
- 5) **Is there a specific data volume threshold, above which your agency would consider the data resource to be "big data"?**
 - a. For a new dataset, is there a specific data volume above which special planning would be required to support and maintain the data?
- 6) **Does your agency currently utilize remote sensing datasets from NASA or another agency?**
 - a. If so, do you have any recommendations to improve the data services available from NASA (or another agency)?
 - b. If you do not use NASA data, are there particular barriers to accessing or using the data that you have encountered (e.g., difficulty finding relevant data, lack of metadata, data formats not compatible with our geospatial software tools, lack of documentation and training resources, documentation of data accuracy not sufficient, benefits of using remote sensing data not well documented)?

Breakout Group #1 – Summary of Answers

- The first breakout group challenged the NASA ASP and WWAO team to be aware of, and take advantage of, existing ground-based data and other commonly used datasets for specific problems. Participants made the point that remotely-sensed data do not take the place of ground-based or other verified data and that they are complementary. (WWAO and NASA ASP representatives commented that they fully recognize and agree with this statement.) Once calibrated to ground-based data, remotely-sensed data can be used to extend or augment existing ground-based data into areas where there are no in-situ sensors.
- Communication among the state water resource agencies leads to a better understanding of best practices. The group encouraged the NASA ASP and WWAO team to stay engaged with the states and to look for opportunities for pilot demonstrations and champion projects for remotely-sensed data.
- A major challenge to “big data” storage and use of cloud computing is related to state statutory inflexibility. The use of certain data and reporting programs are codified within the states’ legal systems and administration of water. In this sense, certain datasets must be held to a legally and politically defensible standard. Case law that includes remotely-sensed data would be a step forward.
- Regarding formatting and accessibility, the group noticed that all of their participating agencies utilized geospatial data. The time-dimension and size of remotely-sensed raster data were also viewed as an important element to investigate. The creation of tools that support access to data is paramount, with USGS’ Earth Explorer mentioned as a game-changer for Landsat data. The group requested the development of better/easier to use processing tools, noting that the complexity of using Landsat data lies primarily with the initial processing of the raw imagery.
- Significant data gaps exist in the consumptive use of water by riparian and agricultural processes, especially at the field-scale. Remote-sensing used in conjunction with groundwater modeling may have significant potential. Landsat data was viewed by the group as too infrequent. Water managers would like to have access to additional fly-overs to get better coverage, especially during cloudy conditions.
- The group’s recommendations to the NASA ASP and WWAO team included a request for a digestible, easy-to-read summary and catalog of NASA water-related datasets, including variable information. This, along with an explanation of how remotely-sensed data can be used to augment datasets that are currently used by water managers (e.g., agricultural data from the U.S. Department of Agriculture), would be most beneficial. The group also requested a more lay-person friendly approach to describing how datasets can be used. For example, a NASA ASP and WWAO playlist on YouTube to explain how remotely-sensed datasets are being used would be very helpful. Other highlights of the discussion revolved around project reporting (with participants citing onerous reporting requirements to



participate in NASA-funded projects), and the inclusion of the economic value of the availability of NASA data in future discussions.

Breakout Group #2 – Summary of Answers

- Group #2 began with the question of data gaps. They identified evapotranspiration (ET) and consumptive use data as one of the most desirable datasets, especially at a statewide scale. Other data gaps included high-resolution data for soil moisture, river channel geometries and estimates of available and current water storage, reservoir elevations, and high-resolution elevation/LIDAR data that could accompany spectroscopy data.
- Regarding formats and accessibility, the group's most common tools included GIS data, use of Python and R for scripting/programming, and Earth Engine for remote-sensing support. Most group members agreed that open source applications were desirable and appreciated that NASA maintains an Early Adopter's program.
- Specific recommendations to the NASA ASP and WWAO team included more easily navigated websites and a request for pre-processed remotely-sensed data. Sharing of data in a variety of formats was requested. The group appealed to the team for greater engagement via outreach and education efforts. State water resources managers would like to see more case studies and examples of how other people are using data, but it should be understandable, possibly as a video, but at least in an easy-to-follow short document. In-person training sessions were also a desired offering.

Breakout Group #3 – Summary of Answers

- Group #3 addressed the question of data formatting and accessibility first. They were most interested in making sure that common data standards and digital (machine-readable) formats were integrated into existing tools. They also would like to see greater integration of clear and complete metadata accompanying any datasets. Data-sharing was encouraged by the group, barring any statutory limitations to doing so.
- Regarding engagement with the NASA ASP and WWAO team, the group asked for more ongoing training and support and more user-friendly documentation. Regional/topical training sessions would be great for addressing local issues. A catalog where a user could posit a "How Do I...?" type question and get at both dataset listings and tutorials/guides would be useful.
- Data gaps identified by the group included the following: Daily ET data at the field scale (~ 30-meter resolution grid cells), crop recognition at the field scale, soil moisture data, snowpack related products included snowpack storage and Snow Water Equivalent (SWE), subsidence measuring and monitoring, general tools for groundwater monitoring, subsurface geo- and hydro-stratigraphy mapping for groundwater monitoring and storage estimation, and increased skill of weather forecasts beyond the two-week forecast horizon.
- Opportunities for greater collaboration between state water resource agencies were of interest to the group. The participants encouraged NASA ASP and the WWAO team to provide additional guidance on how the states might best share data based on their 30+ years of experience. Co-mentoring students and extended visits between state agencies and the NASA researchers were cited as a good way to transfer knowledge and greater understand the states' needs.
- Lastly, the group suggested that there may be opportunities for greater partnering on implementing projects that would benefit from scalable cloud computing, and that this could be a way to mitigate the

risks of this new approach (such as with fluctuating monthly/annual costs) to hosting data and applications.



Breakout Group #4 – Summary of Answers

- Group #4 spent a significant amount of time discussing specific data issues and recommendations. They referred to the current trend of making environmental data more open and accessible. They suggested the use of open source tools wherever possible and a code version control system such as GitHub for collaboration. They discussed WaterML, FGDC GIS and metadata, and the California Open Water Information Architecture (OWIA) project as established and in process standards development initiatives.
- Regarding the question of partnering long-term with a state water resources agency and long-term financial support, the group recommended that the NASA ASP and WWAO team ask the states to evaluate new capabilities and products and connect review of new capabilities to the budget estimation process at the outset of the project. States typically have at least a 2-year lead time between budget request and availability of resources to support an activity, so the earlier NASA can be engaged the better. Development of a joint agency data management plan may help to ease the transition.
- Key to success when partnering with agencies is anticipating different requirements from different states, and even from different agencies within a state. Some may be driven by budgets, while others have a different organizational structure. Connecting project planning and use cases to specific laws, regulations, and requirements within the states (e.g., their reporting environment, water quality statutes, etc.) may increase its traction within the state and prove to be most useful when adapting new tools to actual operations.
- The group discussed many data gaps and suggested a variety of issues that could be addressed with “big data”, remote-sensing, and NASA tools. These included: Suborbital Unmanned Aerial Systems (UAS) incorporation, more Landsat or similar Smallsat/CubeSat missions for increased coverage in the thermal infrared band, increased snowpack runoff and modeling, increased forecasting skill for both droughts, precipitation, and floods, use of remote-sensing for crop classification and increased crop

pest detection, an expansion of the INSAR groundwater subsidence monitoring for groundwater management and fracking impact assessment, aerial electromagnetic imaging for geo- and hydro-stratigraphy mapping, better vegetation mapping, applications specific to the cannabis crop, and real-time flood and inundation maps. Ground-based datasets that may assist with calibration and other tool development include a continuous GPS network, weather station networks, reference ET and field mapping networks for integration across state boundaries.

- Several state agency attendees in the group mentioned their exploration of cloud computing platforms and cited how difficult it was to understand remote-sensing data. They expressed great interest in learning more about how to convert the data into interesting and useful products. WSWC discussed their experience with the cloud when first deploying WaDE with some states and how the cost became unsustainable for the program.
- Specific recommendations made by the group to the NASA ASP and WWAO team were to continue expanding their investigations into ET and consumptive use of water. These would be very beneficial to most of the attendees. Groundwater monitoring and subsidence/recharge monitoring via INSAR were listed as some of the most desired too. The group also asked for a continuation of water quality assessments via remotely-sensed data. A repository of the use of remotely-sensed data in legal contexts related to water and agricultural water withdrawals (methods, metadata, and documentation) would be extremely helpful in breaking down barriers to adoption. The group wished to continue collaboration with the NASA team and hoped that they would continue to foster partnerships and greater communication.



Key Takeaway Ideas from the WIMS Workshop:

1) Management practices within the states evolve over time and each state has a different regulatory, administrative, and operational framework. The best results will be achieved with frequent communication between project partners, by staying engaged with state agencies and looking for pilot opportunities collaboratively. Outreach and education will be key to starting projects with new states and expanding current partnerships. On-going training and support are necessary for a successful transition of research and tools.

2) Websites and tools for data accessibility and processing that are easy to use are very important. Working with the states to build processing tools for remotely-sensed data that they can support is very important. Having a strategy in place with respect to where software and tools will eventually reside is a critical issue that should be addressed as soon as projects commence. Regarding long-term data storage and computational capacity in the cloud, some attendees expressed concern over unpredictable costs with cloud vendors and use of other proprietary data formats and software packages. A preference was expressed to utilize standardized, machine-readable, and interoperable formats for data wherever possible, and that open source software be the default when looking at new project possibilities.

3) There are myriad datasets that need further research, a majority concerning the agricultural sector in the West. Soil moisture, channel geometries, reservoir levels, water quality, vegetation mapping, groundwater modeling, especially at usable field-scale resolution would be very useful to state water resource agencies. These were the primary data gaps identified by the attendees and should be elevated to a higher priority.

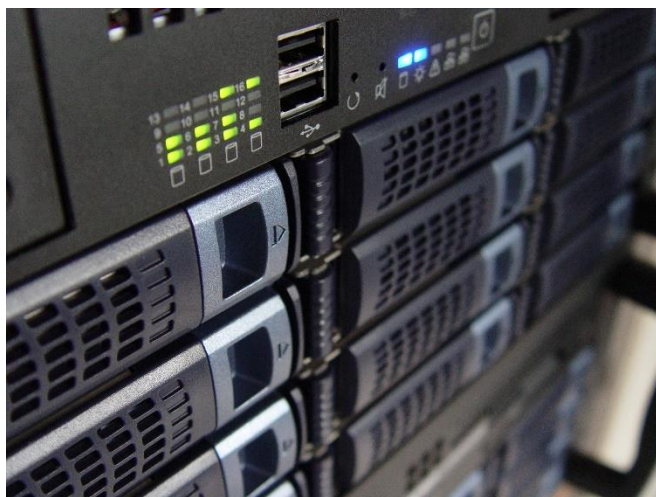
4) Reducing the difficulty related to working with a federal partner would be ideal. The ability to quantify tangible benefits gained by the state agency from a given project is highly desirable and makes the tool more attractive to other partners. It was suggested that on-site training and co-mentoring between state agencies and NASA might be a good way to transfer knowledge and facilitate tool integration into agency operations.



Future Directions

Strategic Considerations for NASA's ASP and WWAO Office

State water resource management agencies play a central role in water management in the western U.S. and are important partners for WWAO and NASA ASP. Understanding the current role of cloud computing within the data management systems operated by western water resource management agencies is an essential first step for NASA in developing a strategy to



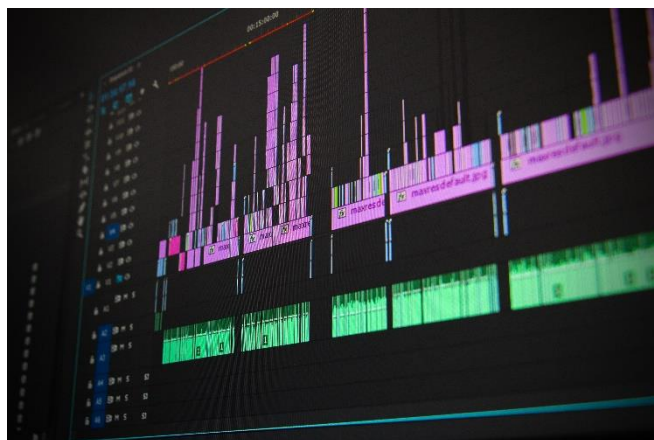
effectively use cloud-based resources. While there is a strong potential for use of the cloud to streamline the process of transitioning new remote-sensing based tools and approaches to operational use in partnership with water management agencies, it is clear that careful planning and coordination will be required to realize these benefits.

The results of the survey and findings presented in this report will be valuable to NASA in providing guidance to NASA-supported projects regarding use of cloud-based resources. Important considerations for NASA identified in this report include not only whether a state agency is currently using the cloud, but also whether the agency is currently hosting geospatial applications (in addition to permitting, reporting and administrative applications), cost considerations associated with data transfer for applications that provide access to large collections of satellite data, and the availability of expertise within an agency to support maintenance of specialized software or models developed as part of the new solution.

Insights provided by this report into the role of centralized IT services within some states will also inform the development of best practices that WWAO in particular might recommend to WWAO-supported projects. For cloud-based applications developed by WWAO-supported projects, it is clear that it will be necessary for project teams to engage not only with key technical staff at water management agencies, but also with the right contacts within the state IT departments. As WWAO continues to expand its portfolio of activities, development of best practices for evaluating the potential for use of cloud computing as part of the transition strategy would likely have benefits both for NASA-supported scientists and agency partners. In addition, WSWC serves an important resource available to WWAO to assist in identifying key contacts within state agencies to help projects evaluate options for transitioning new capabilities to operational use and identify realistic strategies that will have a high chance of success, both technically and administratively.

What Clouds are on the Horizon?

State water resources agencies in the West face myriad challenges when working to complete mission-critical data programs. Most of the agencies consulted are required to procure their IT services and any IT assistance through a Centralized IT Services (CIS) group or agency. The CIS group may or may not be "cloud friendly," and at the very least agencies can expect that use of cloud computing would require either CIS oversight or additional time for data classification and security reviews. Even if the CIS group is cloud friendly, an agency may need to work through additional bureaucratic considerations before they are able to take advantage of cloud computing



and other cloud services. Inflexible budgeting within the agencies may preclude use of the cloud, and many have concerns about access and security of the data.

However; even with this multitude of barriers to entry, many water resource agencies are making tentative steps to include cloud computing in their suite of tools. Some have found using the cloud to be very effective for rapid piloting, meeting user demand and traffic surges, and to achieve a decrease in local hardware procurements and maintenance. The early results of cloud adoption are mixed, but as noted by most of the respondents who have begun using the cloud, they expect their use to increase in the future. This trend is supported by a few first states (AZ, CA, and CO) adopting a “cloud first” policy when looking to implement new applications or procure new hardware. It is likely that, with consolidated IT services, there will be an impetus to consolidate applications in an easy-to-use, easy-to-monitor framework as well.

WSWC will continue to investigate platforms and vendors that make WaDE application deployments

simpler to install, monitor, and gauge usage. Currently WSWC has funding to investigate the potential for cloud deployment. Sustained funding of WaDE in a cloud-hosted setting depends on whether the WSWC member states find value in sharing their data using a common data format and using web services. WSWC continues to develop use cases for the WaDE platform to quantify those benefits to its member states.

NASA ASP and WWA0 will continue to work with their project co-sponsors to evaluate what long-term data management strategies will work best for their partners. This will likely include governance and partnerships that could implement a shared-costs approach to hosting larger remote-sensing datasets, and processing of those datasets in a cloud environment. Now that these issues have been brought to greater light, NASA researchers will approach each project with long term data maintenance and hosting concerns at the forefront and work to address them with project partners from the outset.



Endnotes

Blodgett, D., Read, E., Lucido, J., Slaweki, T. and Young, D., 2016. An analysis of water data systems to inform the open water data initiative. JAWRA Journal of the American Water Resources Association, 52(4), pp.845-858. <https://doi.org/10.1111/1752-1688.12417>.

Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D. and Moore, R., 2017. Google Earth Engine: Planetary-scale geospatial analysis for everyone. Remote Sensing of Environment, 202, pp.18-27. <https://doi.org/10.1016/j.rse.2017.06.031>.

Green, K., Mitchell, R., Becker, P., Copple, J., Cowen, D., Gabrynowicz, J., Moore, R., Spicci, T., Springer, C., Williams, D, Willardson, T., 2013. Cloud Computing: Potential New Approaches to Data Management and Distribution, National Geospatial Advisory Committee – Landsat Advisory Group. <https://www.fgdc.gov/ngac/meetings/december-2013/ngac-landsat-cloud-computing-paper-FINAL.pdf>. Accessed 10/1/2018.

Huntington, J.L., Hegewisch, K.C., Daudert, B., Morton, C.G., Abatzoglou, J.T., McEvoy, D.J. and Erickson, T., 2017. Climate Engine: cloud computing and visualization of climate and remote sensing data for advanced natural resource monitoring and process understanding. Bulletin of the American Meteorological Society, 98(11), pp.2397-2410. <https://doi.org/10.1175/BAMS-D-15-00324.1>.

Larsen, S.G. and Young, D., 2014. WaDE: An Interoperable Data Exchange Network for Sharing Water Planning and Use Data. Journal of Contemporary Water Research & Education, 153(1), pp.33-41. <https://doi.org/10.1111/j.1936-704X.2014.03177.x>.

Larsen, S., Hamilton, S., Lucido, J., Garner, B. and Young, D., 2016. Supporting diverse data providers in the open water data initiative: Communicating water data quality and fitness of use. JAWRA Journal of the American Water Resources Association, 52(4), pp.859-872. <https://doi.org/10.1111/1752-1688.12406>.

Ranger, S. What is Cloud Computing? Everything You Need to Know about the Cloud, Explained. ZDNet, January 24, 2018. Website: <https://www.zdnet.com/article/what-is-cloud-computing-everything-you-need-to-know-from-public-and-private-cloud-to-software-as-a/>. Accessed 10/1/2018.

Tidwell, V.C., Moreland, B.D., Zemlick, K.M., Roberts, B.L., Passell, H.D., Jensen, D., Forsgren, C., Sehlke, G., Cook, M.A., King, C.W. and Larsen, S., 2014. Mapping water availability, projected use and cost in the western United States. Environmental Research Letters, 9(6), p.064009. <https://doi.org/10.1088/1748-9326/9/6/064009>.

Wikipedia. Cloud Computing, update on September 13, 2018. Website: https://en.wikipedia.org/wiki/Cloud_computing. Accessed 10/1/2018.

Willardson, A.G., 2014. Landsat Thermal Infrared Imagery and Western Water Management. Journal of Contemporary Water Research & Education, 153(1), pp.42-48. <https://doi.org/10.1111/j.1936-704X.2014.03178.x>.

Appendix

State Policies Concerning Cloud Usage

Alaska – Not Provided by Survey Respondent, and Not Found Online

Arizona – Policy 1100: “Cloud First” Statewide Policy – May 1, 2018

“The purpose of this policy (Policy) is to outline the use of cloud technologies for all infrastructure, platform and software purchases by all Budget Units (as defined below) covered by this policy in the State of Arizona (the “State”). The goal is to promote and encourage the use of cloud technologies by Budget Units [BUs]....”

“All BUs are required to use commercial cloud computing services and commercial cloud-based applications, for any new information technology investment. Additionally, any information technology upgrades or modernization projects must also leverage cloud computing services and/or cloud application providers.”

Policy can be accessed at https://aset.az.gov/sites/default/files/Cloud%20First%20Policy_0.pdf.

California – State Administrative Manual – Section 4983.1: “Cloud First” Policy – Revised August 2017

“Cloud Computing is an effective method for the secure, agile and reliable delivery of government services in the State of California. Cloud computing enables business programs to enhance service delivery while ensuring the underlying technologies are transparent, ubiquitous, and interchangeable. To harness the benefits of cloud computing, the State of California has adopted this Cloud Computing Policy. This policy is intended to accelerate the pace at which Agencies/state entities will realize the benefits of cloud computing while adequately addressing relevant statutory and policy requirements associated with State IT systems, including information security and risk management, privacy, legal issues, and other applicable requirements.”

Policy can be accessed at

https://www.documents.dgs.ca.gov/sam/SamPrint/new/sam_master/sam_master_File/chap4900/4983.1.pdf.

Colorado – Office of Information Technology (OIT) – “Cloud First” Policy – Revised November 15, 2012

“Given the state of the industry, Colorado’s IT infrastructure and footprint, and the opportunities that are available, Colorado is proceeding with a “cloud first” policy, mirroring the Federal government’s cloud policy. To that end, Colorado is making a deliberate and explicit policy to “cloud first” services. We will proceed with the presumption that new services, applications and major revisions to existing applications will be supported in a cloud-based environment first, unless there are substantive reasons why they should be hosted on the State’s private infrastructure.”

Policy can be accessed at <https://data.colorado.gov/widgets/t7rj-xsmr>.

Idaho – Idaho Technology Authority (ITA) Enterprise Cloud Policy – P1000 General Policies – December 8, 2015

“When considering cloud services, the highest priority should be given to ensuring the security of confidential state data. Agencies are encouraged to evaluate and utilize Cloud Services as a tool for meeting the business needs of the agency. Where practical, agencies are encouraged to consider shared cloud services across agency boundaries to take advantage of economies of scale where practical without jeopardizing the privacy and security of a given agencies data.”

Policy can be accessed at <https://ita.idaho.gov/psg/p1080.pdf>.

Kansas – Executive Branch Information Technology Strategic Plan – 2016-2017

“Project Execution Risk: The current KITO function is a well-intended attempt to provide oversight to Kansas’ largest IT projects. We will transform the existing capability to truly deliver on this intent. Our new applications will adhere to the three-fold principle: Citizen First, Cloud First, Mobile First”

The EBIT Strategic Plan mentions a “Cloud First” policy (above), but any further policy-related guidance from the Kansas Office of Information (OIT) cannot be found. The EBIT Strategic Plan can be accessed at <https://oits.ks.gov/docs/default-source/oitsdocumentlibrary/ebit-2016-strategic-plan.pdf>.

Montana – Not Provided by Survey Respondent, and Not Found Online

New Mexico – Not Found Online

The New Mexico Department of Information Technology website can be accessed at <http://www.doit.state.nm.us/securityoffice.html>.

Nebraska – Information Technology Commission – Technical Standards and Guidelines – 8-607 – July 12, 2017

“The following table contains the acceptable uses of cloud computing by state agencies. The classification of the data to be processed or stored using cloud computing determines the acceptable options. If there is a mix of data classifications, the most restrictive data classification must be used.”

Data Classification	Cloud Deployment Models					
	State Cloud	Private Cloud	Government Community Cloud	Community Cloud	Public Cloud	Hybrid Cloud
RESTRICTED	✓	△	△	△	⊘	△
CONFIDENTIAL	✓	△	✓	△	⊘	△
MANAGED ACCESS PUBLIC	✓	✓	✓	✓	✓	✓
PUBLIC	✓	✓	✓	✓	✓	✓

- ✓ means an approved deployment model for cloud computing;
- ⊘ means an unapproved deployment model for cloud computing; and
- △ means prior approval by the Office of the CIO is required.

Policy can be accessed at <http://nitc.nebraska.gov/standards/8-607.pdf>.

Nevada – Information Security Committee – Control Number 134 Revision C – March 29, 2018

“Cloud computing is an enabler of business and information management in state government. However, an unmanaged cloud environment will create enormous risk to the State and its agencies. An enterprise governance standard is necessary to prevent a next generation of legacy systems and provide the best solution and/or business value to meet the ever-changing demands of State of Nevada agencies as we move safely and securely into the next era of digital business systems/solutions.

This standard is not to be misinterpreted as requiring any state agency to utilize Cloud Hosting. This standard establishes a baseline security standard for the State of Nevada. Agencies with security requirements exceeding this standard are encouraged to adopt a separate standard containing those requirements. No agency may adopt a standard with lower requirements than this standard.”

Policy can be accessed at

<http://it.nv.gov/uploadedFiles/ITnv.gov/Content/Governance/dtls/Standards/134CloudHosting.pdf>.

North Dakota – Not Provided by Survey Respondent, and Not Found Online

Oregon – Office of the State Chief Information Officer – OSCIO Statewide Policy - No. 107-004-150 – July 18, 2016

“This cloud computing policy establishes standards to ensure that state agencies:

- appropriately analyze and document the benefits, costs, and risks to the state before contracting for a cloud solution;
- assess the readiness of a cloud vendor to deliver a solution that meets the state’s requirements; and
- conduct planning to ensure that state information and financial assets are appropriately protected when adopting a cloud solution.”

“Strategic Considerations: The choice of a cloud solution over a custom built or agency-maintained system can have substantial, long-term impact on agency capabilities, business processes, and investments. Agencies should carefully consider the strategic implications of this sourcing decision, including how it will affect the organizational capabilities of the agency; whether the service is likely to serve agency long-term goals, and how the service and data will integrate with other state services and data to support service delivery and ongoing innovation.”

Policy can be accessed at <https://www.oregon.gov/das/policies/107-004-150.pdf>.

Oklahoma – Not Provided by Survey Respondent, and Not Found Online

South Dakota – Bureau of Information Technology – Data Center General-Data Center Security – Cloud-Based Services and System Information – Section 230.9.1 – June 1, 2018

As the approving entity for all statewide IT services and systems, including cloud-based services and systems, BIT must review, approve, and be a signatory to all agreements for acquiring or using cloud-based types of systems or services. Cloud-based technology providers include, but are not limited to, any entity that uses technologies and business processes to store, access, or manipulate state or citizen data from outside the direct physical or logical control and management of BIT managed systems. It is critical to plan ahead for the purchasing of these services from an IT or cloud provider. Agencies must factor in the time required for BIT staff to perform a detailed review and assessment to determine whether approval can be granted.”

Policy can be accessed at <https://bit.sd.gov/docs/Information%20Technology%20Security%20Policy%20-%20Contractor.pdf>.

Texas – Cloud Services Guide for State Agencies and Institutions of Higher Learning – December 2014

“Cloud computing delivers managed information technology (IT) services. This approach provides convenient, on-demand delivery of information, as well as IT flexibility, efficiency, and cost savings for government. Texas agencies and institutions of higher education (agencies) are authorized and encouraged to consider cloud services for information resource projects. The 83rd Legislature, through the passage of House Bill 2422 (Gonzalez), authorized state agencies to consider cloud services for major information resource projects.

Although cloud services are relatively new in the public sector, the model has been tested and is sufficiently mature to be adopted by Texas agencies (see Lessons Learned: Pilot Texas Cloud Offering – PDF). The Texas Department of Information Resources (DIR) has included cloud services as one of the top technology priorities for Texas state government in the 2014–2016 State Strategic Plan for

Information Resources Management. DIR has developed tools and resources for agencies to evaluate cloud solutions and determine benefits and appropriateness of such solutions.

Cloud services can be highly beneficial when properly implemented in appropriate circumstances, but they are not the answer to every IT need. Cloud services can pose their own special risks, as can any powerful and innovative service delivery model. Agencies should always examine all the issues relevant to their data and circumstances before determining whether and how to implement any cloud solution.”

Guidance document can be found at

<http://publishingext.dir.texas.gov/portal/internal/resources/DocumentLibrary/Texas%20Cloud%20Services%20Guide.pdf>.

Utah – Department of Technology Services Cloud Computing Strategy – June 21, 2017

“Cloud computing offers state government a number of potential benefits such as reducing the total cost technology ownership or improving your state’s ability to respond faster to market opportunities. Utah was the first state to develop a strategy for how it would leverage cloud resources and has leveraged many cloud resources as a way to supplement and add value to traditional computing environments.”

Documentation available at <https://dts.utah.gov/state-of-utah-cloud-computing-strategy>.

Washington – Office of the Chief Information Officer – Securing Information Technology Assets – Standard No. 141.10 – December 11, 2017

“Agencies are responsible for adherence to these IT security standards to protect IT systems and applications, whether they are operated by or for an agency, and whether they operate internally on the SGN, or external to the SGN. Examples of environments external to the SGN include the Inter-Governmental Network (IGN), the Public Government Network (PGN), business partner hosted services and cloud services.”

From Washington OCIO’s “Understanding the Cloud” documentation:

“If the state wants to meet the goal of providing a mobile, efficient, responsive, open and secure government for the citizens of Washington, cloud services must be part of the overall technology strategy. While it is ultimately, up to an agency to determine when it is appropriate to use cloud-based solutions, the agency should consider cloudbased services first.”

Policy can be accessed at <https://ocio.wa.gov/policy/securing-information-technology-assets-standards>.

“Understanding the Cloud” documentation can be accessed at

<https://ocio.wa.gov/sites/default/files/public/Understanding%20the%20Cloud%20V3.pdf?wi3c4vlsor>.

Wyoming - Not Provided by Survey Respondent, and Not Found Online