Features of Controlling the Large-Scale Cyber-Physical Water Supply Systems in Cities of Different Countries

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***Abstract*—This paper describes control models of large-scale cyber - physical water supply systems in cities of various countries-Asia (China and Singapore), the United States, England and Europe, and Russia are analyzed. Deficiencies in control models were identified due to current potential threats of water scarcity, degradation of water sources, and risks of chemical and biological contamination.**

***Keywords*—smart city, cyber-physical systems, digital water utility**

I. INTRODUCTION

Researches of the current state of water resources in various countries - Asia (China and Singapore), the United States, England and Europe, and Russia-were conducted in order to form a list of features of management models for cyber-physical water supply systems in modern cities. The level of water availability and availability of water resources were assessed. The primary assessment is based on an analysis of existing approaches to state resource management and water management strategies. In addition, the existing basic problems in the field of water supply faced by the analyzed countries are analyzed. Based on the problems of the water supply industry, an approach to management models of cyber-physical water supply systems in modern cities has been formed. Features of water supply automation, data exchange centralization, and implementation of typed solutions in smart cities are identified. Special attention is paid to the problems of managing cyber-physical water supply systems in modern cities due to the complexity of construction, the emergence of additional threats to ensure the safety of systems, including cyber threats.

II. FEATURES OF MANAGEMENT MODELS FOR CYBER-PHYSICAL WATER SUPPLY SYSTEMS IN BUILDING SMART CITIES

A. *Asia (China and Singapore)*

Water-related problems have seriously hindered China's economic development, especially in recent decades. The country's leadership has decided to modernize the approach to water resources management. In order to achieve the goals set for the recovery and development of the national economy, as well as to solve the problem of water scarcity, the Chinese "water agenda for the twenty-first century" was formulated in 1998. This document focused on the implementation of this strategy and discussed China's approach to addressing its water scarcity problems in order to ensure sustainable socio-economic development [1].

The technological development of the Asia-Pacific region has also affected the management of large-scale cyber-physical water supply systems in the construction of smart cities. Rapid economic growth has required changes in water management strategies. Urbanization has required increased requirements for water resources, their quantity and quality. Established industrial enterprises that produce products for many sectors of the world economy also required a significant amount of water.

The Northern part of China is water-deficient. In order to solve this issue, it was decided to build the South to North canal for the residents of the Northern provinces, including the capital Beijing. A similar water transfer project was implemented in the Soviet Union-the Severo-Krymsky canal in order to provide water to the Crimean Peninsula. In addition, China has established and successfully implemented water resource management and conservation strategies. The purpose of the strategic documents is to improve the country's water security.

However, despite the existing strategic approach to water management issues [2] indicate that there are problems in Western China. Since the 21st century, glaciers in Western China have been melting at a very high rate; lakes on the Tibetan plateau have expanded rapidly, but lakes in other regions have been severely affected by people; and groundwater in the North China plain is increasingly being depleted. In General, the country's water resources are reduced by about 9.6 billion cubic meters annually, and water policy needs to be reviewed.

The phenomenon of Singapore's efficient water management is indicative and a reference for many modern cities and countries. The peculiarity of this phenomenon is historically determined. During the period of Singapore's forcible withdrawal from Malaysia, which occurred during violent confrontations, the Malaysian government excluded Singapore from the country. In 1965, Singapore officially declared its state independence. In the 1990s, imported water from Malaysia became increasingly vulnerable due to the deterioration of diplomatic relations. Singapore has decided to use reverse

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osmosis to reduce its dependence on Malaysia. Subsequently, the water authority was connected to global industry networks, technologically and institutionally reconfiguring the state through integrated management, corporate intermediaries and strategic nodes. By 2060, reverse osmosis technology is expected to provide 85% of the water supply [3].

Singapore uses a combined cyber-physical water system control model to balance the economic and environmental costs of a three-stage urban water supply system. It includes the processes of production, distribution and purification of water. Taking into account different attitudes to the growing imbalance between water supply and demand, three hypothetical scenarios have been developed [4], based on which three sets of data on water demand and wastewater production volumes have been determined. A simulation of the application of a combined approach to the use of water resources in Singapore was carried out. The proposed two-purpose model allowed to form a management understanding of the use of alternative water resources. For example, in 2020, the water demand is modeled as 5.63 x 10 (8) m3. After optimization using the proposed model, the amount of alternative water is 2.5 x 10 (8) m3 (local catchment water), 2.5 x 10 (8) m3 (imported water), 5.31 x 10 (7) m3 (desalinated water), 4.05 x 10 (7) m3(New water for indirect drinking use) and 8.10 x 10 (7) m3 (New water for direct use). The total water supply is 6.75 x 10 (8) m3-this means that there is some redundancy in the water supply. In addition, indicators of supply and demand, economic costs, and environmental costs help determine the appropriate planning period. In General, the proposed model balances the trade-off between the risk of increasing future supply and demand imbalances and the current adequacy of water resources. It was found that integrated management and a long-term strategic approach to water resources management contributed to achieving the best results in the field of water security in Singapore. The integration of water supply and sanitation services into a single Agency contributes to the introduction of water reuse throughout the city.

B. *United States of America*

Modern digital technologies are actively used in the field of improving the management of cyber-physical water supply systems in modern us cities. Considering the features of control models of cyber-physical water supply systems in the construction of smart cities, it is important to pay attention to the use of an integrated approach. An integrated approach is presented by solving existing problems in the water supply industry, using modern technologies to improve management efficiency, as well as neutralizing potential system vulnerabilities. In the US, as in many countries, there is increased wear and tear of water supply systems, which leads to increased water losses. The problem of detecting and locating water losses has received much attention in recent years [5]. Due to the zonal separation of the network, scenario modeling of the normal operation of the pipeline network and comparison with the actual indicators from the equipment, it allows you to determine the location of the leak zone. By implementing an approach to detecting and localizing leaks in water distribution networks using digital technologies, the US plans to significantly minimize losses and, as a result, improve management efficiency.

The main threats are water scarcity in large agglomerations, potential contamination and contamination of water supply sources, natural precipitation management - preventing flooding of the city by modernizing water disposal systems, as well as threats to cyber-physical security. An example of a large-scale water source reservation system in New York city. By this project, the level of strategic security of the largest city in the United States has increased by reserving water sources. If we consider the introduction of monitoring systems for the state of water bodies, we have introduced requirements for water quality control using cyber-physical systems for local and remote monitoring. Mobile stations for analysis and monitoring of key water indicators are installed on the reservoir. Information from this equipment is sent to the control and analysis center. In addition to qualitative indicators, quantitative indicators are measured in reservoirs. In the city of Chicago, the problem of managing natural precipitation was solved with the help of an additional channel "Chicago Deep Tunnel", connected to one of the largest quarries of Thornton. It is located in Thornton, Illinois, South of Chicago. This quarry is a reservoir for reducing the backflow of storm water and wastewater from the Chicago rivers to lake Michigan. In turn, Philadelphia - the fifth largest city in the country, opposes the policy of Chicago on storm water management. Philadelphia city officials have announced plans to spend $ 2.5 billion from 2011 to 2036 to turn 10,000 acres of Philadelphia into green space, thereby turning the city into a "sponge" and preventing possible flooding.

The use of programmable logic controls, sensors, valves, and dispatch control and data acquisition (SCADA) systems in water distribution systems has allowed them to become more intelligent. The increase in the number of digital equipment and the availability of intelligent control systems increases the level of vulnerability to malicious intrusions and cyber-physical attacks. Due to timely changes in the architecture of building smart cities in the United States, it became possible to increase the efficiency of using modern technologies in smart cities.

Considering possible security incidents of the water supply management system, the rules of correlation of security incidents are formulated, as well as modeling and identification of these events on the developed prototype model of the water supply management system. The target system responds to the following events: changing the water level in the tank; changing the water pressure in the tank; changing the water flow through the lock; changing the state of the gate. For any of these events, the system performs analytical processing of data in terms of their correlation and the formation of security incidents.

A security incident is formulated as a pair (I, t_0), where I is a set of interrelated events that occurred in the system during the time period t_0. The formation of an incident indicates the presence of an attacker's actions aimed at violating one or more information security requirements. In General, the event correlation rule looks like this:

$$\left(\{ev\quad sw_i\}_i \cup \{ev\quad ph_i\}, t\right) \to Type_{Inc} \qquad (1)$$

where $ev\quad sw_i$ is the set of events program-information nature, $ev\quad ph_i$ — events of a physical nature, the implementation of which within a fixed time period t, determines whether there is incident of a given type $Type_{Inc}$

Identify applicable funding agency here. If none, delete this text box.

Reducing the likelihood of a cyber-attack on the infrastructure of water supply management is achieved through reduction of system vulnerabilities. Data from hardware is encrypted, access to it is restricted and controlled. Potential vulnerabilities of large-scale cyber-physical systems are tested, taking into account existing systems and potential threats [6].

Despite the creation of modern large-scale cyber-physical water supply systems in the United States, such as the water reserve in new York, the construction of a tunnel to divert stormwater in Chicago. Strategically, cities are becoming dependent on the owners of water supply systems. Private equity firms and water-focused investment funds are significant investors in private companies that manage municipal water management operations in the United States. This led to the fact that most of the state water infrastructure in the country was privatized and held by international investors as securitized assets. [7]

C. England and the European Union

In the period from 1990 to 2012, a lot of work was done to analyze the current state of water resources, the census, the assessment of the level of pollution of sources and their classification. The European Union's water management policy has contributed to improving water quality in the member States [8]. Here is an example of management models:

- “German model” with joint-stock companies usually owned by local authorities;
- “French model” with a high share of public-private partnership;
- “English model” with water supply infrastructure privatized according to the basin principle (and not according to the settlement principle).

In addition, in continental Europe, investment in this sector is usually attracted through government loans (i.e. municipal bonds), even in the case of public-private partnerships. The reason for this is quite pragmatic: public loans are cheaper than private ones. It is of fundamental importance that investments are rarely made from the current budget, and loans are repaid through the economic activities of water supply companies [9].

A feature of control large-scale cyber-physical water supply systems in smart cities in England and Europe can be described as the standardization and use of BIM - Building Information Modeling technologies, as well as equipping cities with IoT devices. When designing smart cities in England, it was decided to create smart city standards based on BIM technologies. This allowed us to get a comprehensive view not only of a specific system, but also of the relationship and dependence of the spectrum of systems between each other. These standards have become reference standards for many countries and are used as a basis for both the application of BIM technologies and the

The architecture of building smart cities in England and the European Union, by equipping distributed sensors and real-time monitoring, analysis and management equipment, has led to an increase in system vulnerabilities as a result of potential threats to the functioning of cyber-physical water supply systems. Many cyber security issues are the result of system integration. Ensuring security at both the Internet of things and the network level is critical to the overall operation of the system. Compared to physical network layer components, these smart sensors connected to smart devices are the heart of cyber-physical water supply systems and are involved in the decision-making process. Compared to the physical network layer, linked data is easier to choose as a hit point and even more vulnerable to cyber-attacks, because hackers destroy critical components of cyber-physical water systems or steal the most important data stored in the database (figure 1).

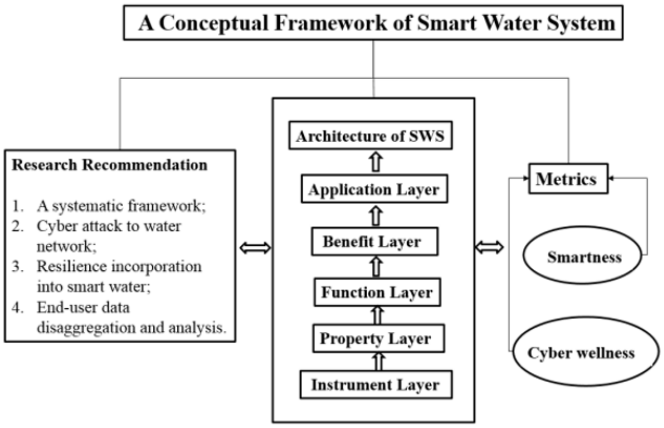

Fig. 1. The architecture of the smart water system

The latest information center and data center systems are vulnerable to hackers. Existing security problems when using the Internet of things is a serious public problem. To date, few studies have been conducted on the protection of cyber-physical water supply systems. Various intelligent devices, such as sensors, recorders, and controllers, play different roles in water supply systems. At the same time, they represent a serious vulnerability in the functioning of systems. When designing systems, it is necessary to develop effective methods and technologies for evaluating the effectiveness of protection of smart water micro-components [10].

D. Russian Federation

In Russia, the approach to managing cyber-physical water supply systems in building smart cities is at an early stage. Existing problems in the water supply sector require significant investment. There is increased wear and tear of both water supply systems and equipment. At the moment, there are two parallel state projects:

- Safe city-supervised by the Ministry of emergency situations.
- Smart city-by the Ministry of construction and housing and utilities.

Unified standards for building smart cities have not yet been adopted at the state level. The use of BIM technologies is in the initial phase - the first state standards have been adopted, our own Russian software is being created, and the first experiments of passing state expertise using BIM technologies are being implemented. Figure 2 shows a structural model of the water supply control system [10], describing the main components of the system and its architectural features. I/O devices include specialized sensors and actuators. Sensors are responsible for receiving measurements related to specific physical processes. This allows us to present a top-level cyber-physical model of water supply control system.

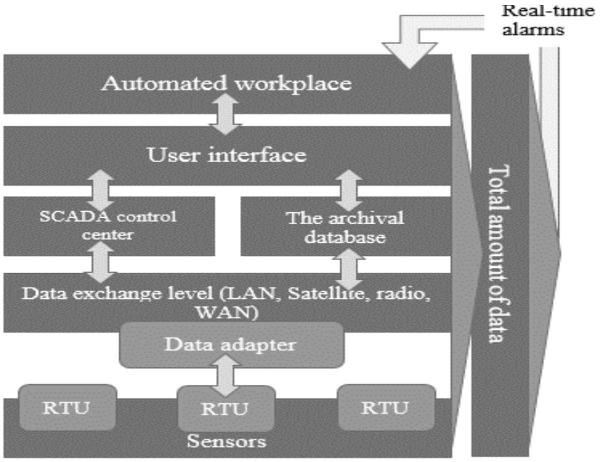

Fig. 2. Model of water supply control system

Despite the high level of availability of water resources and relative accessibility, the risk of water scarcity remains, and there is no classification of chemical and biological infections. Management models of cyber-physical water control systems have increased risks. Along with potential man-made and man-made emergencies, as well as the emergence of additional vulnerabilities in the event of a transition to management using IoT devices and other digital equipment for the water supply infrastructure of modern cities. Strategic approaches to water resources management in other countries have proven to be effective. The Russian Federation also needs to take into account existing vulnerabilities and threats when standardizing modern cities, water management, and improving strategic security.

III. Conclusion

An assessment of the strategic approach to managing cyber-physical water supply systems in modern cities in Asia (China and Singapore), the United States, England, Europe, and Russia revealed management shortcomings. The disadvantages are related to potential threats of water scarcity, degradation of water sources, and risks of chemical and biological contamination. Using innovations to create smart cities often does not solve the existing potential risks of water scarcity. In most cases, modern cities have a single source of water supply, and the architecture of building cyber-physical systems requires improvement. Based on the management models of cyber-physical water supply systems and existing potential threats, a list of features of management models for managing large-scale water supply systems in modern cities is formed. Improving the management models of cyber-physical water supply systems is aimed at creating backup water supply sources and equipping water quality monitoring systems. Redundancy reduces the risk of water scarcity in emergencies and climate change. Monitoring systems make it possible to increase the level of control over the actual consumption of resources and improve water quality. Of course, additional equipment requires costs and compliance with the safety of its use. Cyber threats of modern management systems are a special form of threats that must be taken into account when modernizing modern city architectures. The formed list of features of models of management of large-scale water supply systems of cities of various countries became the basis of simulation of management of cyber-physical water supply systems of modern cities.

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