Optimal Allocation and Integrated Dispatch of Regional Water Resources in Yunnan Province — Problems and Countermeasures

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Abstract. Amid rapid economic growth, the contradiction between water resources carrying capacity and distribution of productive forces have escalated, indicating the increasing barriers that water shortage and pollution have posed to sustainable development of the economy and society. China has currently entered an age of “new normal” in economic progress, during which constraints are imposed on resources and environment, ecological products become more indispensable, while infrastructure connectivity, and mechanism innovation appear more essential. Therefore, it remains important to dive into how to proactively implement the water management policy of the new era. The policy advocates overall planning and integrated management, requiring relevant agencies to comprehensively enhance the security of water availability and scientific management capabilities to resolve prominent problems of systematic management and coordination between the market and government under the premise of prioritizing water conservation and promoting spatial water balance. This paper conducted a preliminary analysis of problems about water resources allocation and dispatch management in some key areas of Yunnan Province and raised targeted suggestions including innovation in management mechanisms and approaches, and promotion of integrated management and scientific dispatch of water resources. The purpose is to provide some references for Yunnan about its integrated allocation and dispatch management of water resources in key areas and the network of major water supply projects.

1. Introduction
In recent years, Yunnan has been committed to addressing water pollution, issues about ecological civilization, and the imbalance between temporal and spatial distribution of water resources and economic and social development. It has successively completed a series of water conservancy projects, among which are Niulanjiang River-Dianchi Lake Water Diversion Project, Chemabi Reservoir, three connected reservoirs for water transfer in Erhai, and water diversion project in eastern Yuxi. Meanwhile, it has commenced to construct the network of water supply projects, which is dominated by water transfer projects in central Yunnan, supported by large and medium-sized water supply projects, and supplemented by the projects of comprehensively utilizing water resources from hydroelectric stations. Greater efforts are made to restore nine plateau lakes including Dianchi, Erhai
and Fuxian Lakes. Key areas of water management come into existence centering around urban clusters such as Kunming, Qujing and Dali with industrial and agricultural development, plateau lake management and aquatic ecosystem conservation on the agenda. Significant engineering measures are implemented to allocate water resources based on overall planning, mitigate the imbalance between water supply and demand, and optimize water environment management and aquatic ecosystem conservation. As a result, extensive management mode typically adopted before proves incompatible with water management ideas of the new era and no longer meets the requirements of economic and social development. This paper conducted a preliminary analysis of problems about integrated allocation and dispatch management of water resources which currently confront some key areas like urban clusters in central Yunnan and plateau lakes that are plagued by water scarcity, fragility of aquatic ecosystems and water degradation, and provided relevant countermeasures and suggestions. The aim is to help the key areas of Yunnan improve their integrated management of water resources, refine dispatch management skills, and maximize the role and overall benefits of water conservancy projects in flood control, water supply, water pollution abatement, aquatic ecosystem restoration and social environment improvement.

2. Changes in Dispatch Management of Regional Water Resources

Yunnan Province is situated in the origin and upstream area of various rivers, rich in total water resources, which, nevertheless, appear hugely uneven in seasonal and geographical distribution. Imbalance between water supply and demand remains acute due to the temporal and spatial mismatch of water and land resources, whereas engineering issues, limited quantity and poor quality all underlie water shortages. In particular, central Yunnan registers a constant increase in water demand, where water resources carrying capacity proves severely inadequate, which is exacerbated by the potential risk of water pollution and aquatic ecosystem degradation. Yunnan Province has made an overall plan and proposed building a large three-dimensional, comprehensive and multi-functional water network featuring “river-lake link, west-east water diversion, complementarity among multiple sources, and mutual support within the region” and an engineering layout with water systems connected, aiming to resolve problems about regional water scarcity, water environment improvement and aquatic ecosystem conservation. It has long been promoting the construction of water conservancy infrastructure and has successively completed or launched a series of significant water conservancy projects, such as Niulanjiang River-Dianchi Lake Water Diversion Project and the water transfer project in central Yunnan, which provide strong support for people’s daily life and production as well as the harmonious development of society.

Management of water conservancy projects and water dispatch vary profoundly and differ in characteristics at different times as development ideas are constantly adjusted, the relationship between supply and demand transforms and practical experience accumulates. Water conservancy remained in its infancy in the era of planned economy, during which management philosophy and techniques of water conservancy projects proved backward and management approaches were undiversified and unorganized owing to the underdeveloped economy at that time. Under the circumstance that the imbalance between supply and demand was slight, water was largely available on demand, while management was dominated by extensive, static mode, which resulted in a severe waste of water. During the period of China’s reform and opening up, the rapidly growing economy continuously boosted demand for water resources, making the contradiction between supply and demand a bottleneck impeding the sustainable development of economy and society. At that time, water conservancy work centered around engineering construction, water demand was determined based on supply under the premise of moderate conservation, and the scope of management extended from a single project to a sub-region. The outdated traditional management mode emphasized construction but neglected regulation, a problem which was underestimated. Responsibilities for water management overlapped among different administrative agencies, compromising efficiency and benefits. In recent years, industrialization and urbanization gradually accelerated and human activities and climate change exerted greater influence on water resources, the development conditions and
carrying capacity of which were not as favorable and adequate as expected. As a result, previous water conservancy projects that solely aimed to supply water started shifting towards regional water allocation projects intended for water supply, quality improvement and ecological conservation. Water sources and users diversified and the projects were characterized by long distance and large flow due to the need to realize multiple targets and the increase in water supply tasks. Accordingly, allocation and management in a single small region began to switch to cross-regional and inter-basin dispatch of multiple sources and integrated management.

As reform advances, China takes “building an ecological civilization” as its goal and proceeds to put into practice “the strictest water management system’. In particular, the report to the 19th CPC National Congress has incorporated green development into the economic development model, which brings sustainable development to new heights. The relationship between water supply and demand continues to change, requiring to “determine the scale of city, land, population and production based on water resources and adjust measures to water conditions’ under the premise of in-depth water conservation. Current water management mode has difficulty meeting the development needs, which must switch from extensive, static and traditional pattern to intensive, real-time dynamic and information-based mode by utilizing big data. Only an integrated management mode can satisfy the requirements of joint dispatch and coordinated control of water from multiple sources within the region and help realize comprehensive targets, which will become normalized in the future.

3. Major Problems about Dispatch Management of Regional Water Resources

Given the reform and development requirements of water conservancy proposed in the new era according to novel situation, it is necessary to shift water supply method, the relationship between supply and demand and management mode by integrating multiple cross-regional projects within a large area, jointly dispatching water resources and comprehensively managing multiple tasks. Nevertheless, decentralized management of water dispatch among industries and departments is still common in Yunnan Province, which considerably lags behind developed areas in management. Analysis suggests that water management in Yunnan is impeded by three major problems:

3.1. Current management mode cannot meet the requirements of managing the multiple targets of water resources in a coordinated way

Dianchi Lake basin in Kunming, Qulu dam region in Qujing, Erhai basin in Dali, and the eastern sub-region and the “three lakes” area (i.e. Fuxian, Xingyun and Qilu Lakes) in Yuxi remain key areas of Yunnan Province that are prosperous and densely populated, suffering acute imbalance between water supply and demand despite extensive development and utilization. They are also typical areas plagued by various problems about water environment improvement, aquatic ecosystem restoration and water management, which prove onerous and difficult to resolve. Currently, barriers among different departments and regions, and overlapping of functions and fragmentation in public administration remain prominent problems affecting water management and water environment improvement due to the large number of departments involved. Meanwhile, it is difficult to jointly manage and schedule the tasks pertaining to regional water resources, water environment and aquatic ecosystems and the operation of relevant projects owing to institutional constraints, imperfect system, and the lack of organizations and corresponding mechanisms to implement integrated and coordinated management, which greatly lower working efficiency. For instance, Dianchi Lake basin has built cross-regional water diversion and river-lake link projects in recent years, including Zhangjiu River, Qingshuihai Lake and Niulanjiang River, aiming to supply water Kunming requires for production and daily life and the improvement of Dianchi Lake. The urban water supply system of “seven reservoirs and one station” has taken shape that is dominated by Yunlong, Songhuaba and Qingshuihai Reservoirs and supplemented by other small and medium-sized water supply projects. Meanwhile, a comprehensive pattern covering multiple water sources has come into being to achieve the multiple targets of water supply, water environment improvement and aquatic ecosystem conservation, with Niulanjiang River-Dianchi Lake Water Diversion Project supplementing ecological water and supplying emergency
water to cities. Nonetheless, affairs of water management and water environment improvement of Dianchi Lake are jointly administered by various departments and units from the three levels of province, city and county. Some management functions overlap and remain fragmented, while coordination mechanisms are unavailable, which lowers the efficiency of water dispatch management and makes it difficult to maximize the benefits of optimal allocation of water resources and comprehensive improvement of water environment. As another example, Yunlong and Songhuaba Reservoirs in Kunming are two important sources of water supply that lack a scientific and reasonable scheme for joint dispatch due to conflicts of interest among different departments. Yunlong Reservoir has supplied water to Kunming for over ten years since 2007, during which its water level was below the level of dead water in 2012 and 2015 due to long-term excessive supply without regard to the maximum limit based on design, resulting in water unavailability. Additionally, Songhuaba Reservoir once had to release floodwater in the flood season because of excessive storage arising from oversupply of Yunlong Reservoir, leaving water resources that should have been fully and rationally utilized wasted. Moreover, administrative reply requires that any water transferred in Niulanjiang River-Dianchi Lake Water Diversion Project be diverted through the clean water channel of Panlongjiang River into the outer waters of Dianchi Lake. However, over a quarter of the total water transferred, which stands at more than 700 million m³, has been channeled through Yudai and Daguan Rivers into Caohai (literally meaning “grass waters”) of Dianchi Lake since May 2015 in order to meet the standards of water quality assessments, even though the clean water channel of Caohai has not yet started to operate. Consequently, water transferred into the outer waters of Dianchi Lake proves severely inadequate, making it difficult to achieve the annual target of water quality as planned. Clean water running into Caohai is contaminated by original turbid water, offsetting the effect of water quality improvement, while Panlongjiang River and Caohai come under increasing pressure of flood control in the flood season. Therefore, the model of “multiple departments managing water and controlling pollution without reaching consensus” lowers the efficiency of water management. As a result, water available remains limited, and it is hard to maximize the comprehensive benefits yielded by optimal allocation and efficient utilization of water resources.

3.2 Guarantee system for integrated dispatch and management of water resources appears unsound and imperfect

Guarantee system provides essential backup for the integrated management and scientific dispatch of water resources, whereas current management approaches of Yunnan Province still abound with flaws. Firstly, the coordination mechanism remains unsound. For instance, Niulanjiang River-Dianchi Lake Water Diversion is a cross-regional project for ecological water recharge that should be managed without neglecting its connection with water allocation and water environment improvement of Dianchi Lake. Nevertheless, since the current management system allows seven units at the provincial and municipal levels to take charge tasks within the scope of their duties, fragmentation in public administration occasionally happens, leaving many efforts in vain. A large number of units are involved, the management system appears complex, and there is a lack of sound coordination mechanisms at the provincial level. In consequence, annual plan for water transfer from Niulanjiang River to Dianchi Lake frequently fails to be effectively implemented, while it is even more difficult to jointly allocate and dispatch regional water resources in Dianchi Lake basin.

Additionally, the regulatory mechanism has not been effectively implemented. Various measures have been taken for the integrated management of Dianchi Lake, giving impetus to industrial restructuring and relocation in Kunming. Currently, the industry in Dianchi Lake basin basically transfers to Anning City and Fuming County, whereas agriculture moves from Chenggong and Jinning around Dianchi Lake to Songming in Niulanjiang River basin. However, agricultural restructuring around Dianchi Lake has long been stagnant since supervision of water conservancy, environmental protection and agricultural systems lacks coordination. Heavy use of water, fertilizer and pesticides during planting in greenhouses persists in at least 52,900 mu (around 8,715 acres) of land within a 5-km radius along the shoreline of Dianchi Lake, which largely offsets the effect of Niulanjiang River...
Water Diversion Project and slows the improvement of aquatic ecosystems in Dianchi Lake. Moreover, nonpoint source pollution in the upper reaches of Niulanjiang River, which remain a water source region, has not been effectively controlled, indicating that the situation of water pollution is grave. Monitoring results provided by Hydrological Bureau of Yunnan Province suggest that some upstream areas of Deze Reservoir have unacceptably high levels of phosphorus and nitrogen, and river in the upper area of Qixing Bridge in Xundian County registers a continuous decrease in water quality. Consequently, there is a greater risk that poor quality water might be diverted into Dianchi Lake.

Moreover, the policy and regulatory systems are imperfect. Cross-regional water diversion and joint dispatch lack comprehensive laws and systems despite the promulgation and implementation of Regulations on the Protection of Dianchi Lake and Regulations on the Protection of Niulanjiang River. After Niulanjiang River Water Diversion Project was put into operation, only the Regulatory Measures for Niulanjiang River-Dianchi Lake Water Diversion Project and the Joint Dispatch of Dianchi Lake (for trial implementation) was enacted to meet the requirements of joint dispatch of Dianchi Lake, while regulatory system for regional management has yet to come into being. Though relevant policies have specified which non-profit, quasi non-profit and for-profit entities to bear the cost of water conservancy projects, the reality proves much more complex. The primary reason is the diversification of engineering tasks, which also underlies the complexity and difficulty in evaluating project benefits composed of for-profit ones and non-profit social and environmental benefits including aquatic ecosystem restoration and water environment conservation. Projects might fail to operate normally and benefits will not endure if necessary fiscal funds are unavailable to ensure the realization of non-profit benefits and meanwhile income cannot cover the expenditure. This is exactly what happened in Niulanjiang River-Dianchi Lake Water Diversion Project. It has been committed to promoting the public interest of ecology and society since its commencement of operation, during which, however, a long-term mechanism in the procurement of water supply has been unavailable and fiscal funds have not been completely put into place. Water rates and prices have been the focus of controversy when the two sides regulating the supply and purchasing negotiate, while operating funds are still inadequate sometimes. Similar problems have occurred in the emergency water allocation project for ecological conservation in Yuxi’s east sub-region and “three lakes” area (Dalongtan Pool water transfer). Currently, its construction and operation costs remain a huge problem for local government due to the contradiction between funding mechanism and project tasks, in particular the objective of public interest. Additionally, it is imperative to enhance research and introduce relevant policies to help Niulanjiang River Water Source Reserve and the “three lakes” area in Yuxi to fill corresponding gaps in the practice of eco-compensation system, which is China’s novel environmental management system.

3.3 Integrated dispatch and management of water resources are plagued by the weaknesses of technology and lagging pace of capacity building

Integrated dispatch of regional water resources is comprehensive and systematic work requiring scientific management by taking all the water conservancy projects and water resources within a region as an entire system. It aims to comprehensively allocate and efficiently utilize regional water through intensive management of each objective, which comprises real-time monitoring of the hydrological regime and water quantity and quality of each river, reservoir and lake in a region, data analysis, and prediction and early warning of flood and issues about water resources, aquatic ecosystems and water environment. China’s large-scale water transfer projects, such as the middle route of the South-North Water Diversion Project and the Yangtze River-Taihu Lake Water Diversion Project, have largely informatized and intelligentized their integrated management of multiple objectives, including flood control, water allocation, water supply and ecological water dispatch, which greatly enhanced the benefits of water resources and water project management. Yunnan Province considerably lags behind in this aspect. Firstly, it lacks enough capacity to scientifically manage regional water projects and water resources. Integrated dispatch and management are hampered by outdated management techniques and the absence of management organizations and
platforms responsible for coordination and integrated scheduling. For instance, Dianchi Lake basin is an essential region that currently has Niulanjiang River project and Dianchi Lake empirically and extensively managed based on some monitoring stations of hydrological regime and water quantity and quality which are established to support project operation and water environment assessment. Both the automatic hydrological monitoring system in Songhuaba Reservoir and the information system of river chief in Kunming simply center around a single management objective. Regional big data and integrated management platforms have yet to establish for automatic measurement and reporting of hydrological regime and the integrated scheduling of water resources, aquatic ecosystems, and floodwater among rivers, lakes, reservoirs and channels. Secondly, capabilities of water monitoring and supervision are insufficient. Monitoring and supervision of water quantity and quality, aquatic ecosystems, and water projects are the basis of integrated dispatch and management of water resources in rivers, lakes and reservoirs. Currently, monitoring stations in key areas of Yunnan Province are inadequate and poorly distributed, with stations belonging to the departments of water conservancy, hydrology and environmental protection overlapping. Factors monitored and standards are not uniform, and the automation and informatization of monitoring remain at a low level. Monitoring data are kept confidential between each other and information is poorly applied, which are acute problems. A big data platform integrating all kinds of monitoring information to meet the management requirements of each side has not been established. Thirdly, water dispatch management lacks strong scientific and technological support. Investment in the dispatch management of water resources and projects as well as application of modern technologies are not taken seriously, suggesting that emphasizing construction but neglecting regulation remains a serious problem. Yunnan underperforms in research on applied technologies and development of integrated system that could help the entire basin and region to improve integrated scheduling of water project operation, flood control, water allocation and management, water environment protection and aquatic ecosystem conservation. Integrated management of water resources is poorly informatized and intelligentized, while water conservancy is slow to modernize and informatize.

4. Suggestions
In the future, management philosophy of water resources will constantly improve based on the demand of green development, and requirements of water conservation will become increasingly high. Yunnan should further promote innovation in management mechanisms and approaches and especially strengthen the integrated management and scientific dispatch of water resources in key areas, which are necessary to resolve complex problems about water dispatch management in those areas and maximize the comprehensive benefits of water projects and water resources management. To this end, this paper has raised the following suggestions:

4.1. Strengthening and improving system and mechanism building for the management of regional water resources
Yunnan should speed up efforts to design and build better systems and mechanisms for the integrated management of water resources in key areas, and establish a governing body to coordinate all its subordinate agencies at different levels within the region to work together under its united leadership. A provincial-level organization should be established to comprehensively manage the operation of cross-regional water transfer projects (e.g. Niulanjiang River-Dianchi Lake Water Diversion Project) and water resources received in key areas or basins. It matters to build a scientific and efficient management system, a higher-level coordination mechanism as well as supervisory and decision-making platform. Improving the mechanism of consultation, decision-making, deliberations and regulation and clarifying responsibilities and the division of work will help ensure each department and agency to coordinate with each other and make concerted efforts to manage water resources, water environment and aquatic ecosystems. Great efforts should be made to resolve the problem of “multiple departments managing water and controlling pollution without reaching consensus” and improve the capabilities and efficiency of scientific allocation and integrated management of regional water resources.
resources so as to utilize water efficiently and protect aquatic ecosystems and water environment effectively.

4.2. Establishing and perfecting the system of policy, regulation and institution
Establishing and perfecting relevant policy, regulation and institutional systems are the basis for effectively managing water resources in key areas, which refers to water allocation at different levels and multi-objective management, involving various regions and departments with complicated interest relations. Therefore, firstly it is essential to set up and perfect the management system and relevant regulations of project planning, construction control, financing and loan repayment, operation and maintenance, water quantity allocation, water price mechanism, and ecological protection, which will help projects operate smoothly and ensure the intensive management of regional water resources. Secondly, Yunnan should formulate a long-term mechanism to guarantee ecological water, further improve water price management, taxation and collection system, put non-profit expenses in the exact place, and effectively implement the program of ecological water allocation. Thirdly, it should actively conduct policy research on eco-compensation system related to water. The eco-compensation system is suggested to be established based on the principle of “those causing damages are responsible for recovery, those that develop take charge of protection, and those that benefit have to compensate”. Special funds for water conservation should be established across administrative regions to make water quality in protection zones meet the standards and promote the coordinated development of regional economy, society and environment.

4.3. Attaching great importance to the overall planning of regional water dispatch and management
Great attention should be paid to the overall planning of regional water dispatch and management. The first thing is to effectively plan water allocation and be committed to adjusting demand based on water quantity. Water supply schemes for each objective should be integrated under the premise of fully conserving water based on water resources carrying capacity and the principle of “necessity, ecological security and sustainability” to achieve optimal allocation and scientific dispatch. Secondly, monitoring of regional water resources should be well planned and designed. Departments of water conservancy, environmental protection and agriculture must coordinate with each other to optimize the overall planning about the network of regional water monitoring stations in accordance with the needs of regional flood control, water management, water environment improvement and aquatic ecosystem restoration and the assessment requirements of river chief system. It also matters to establish an integrated monitoring system and a management platform that can collect and share information with rivers and lakes, aquatic ecosystems, water resources, water environment and projects dynamically monitored by reasonably distributed and technologically advanced monitoring stations. Thirdly, application system for management should be well planned and designed. Building platforms for integrated management of regional water resources comprises the development and establishment of application systems for water project management, hydrological measurement and forecasting, command of flood prevention and drought control, water supply prediction, water allocation and dispatch, water pollution prevention and control, and ecological restoration. Each application system needs to be well planned and designed based on the model of “a unified network, database, platform and map” to meet the requirements of multi-objective management of regional water resources.

4.4. Making greater efforts to informatize and intelligentize the intensive management of water dispatch
Informatization remains an important way to realize the intensive management of regional water dispatch. It is of importance to accelerate the transformation of management approaches, maximize the ability of water science and technology to support management, and comprehensively strengthen the capacity of integrated water management based on big data, which prove indispensable for accurate coordination and scientific management of cross-regional water diversion involving multiple sources so as to complete various objectives and tasks, and for economical and efficient utilization of water.
resources. Firstly, the region and basin are supposed to establish and perfect the network of monitoring stations to monitor hydrological regime, water environment, aquatic ecosystems and project conditions. Big data, cloud computing and artificial intelligence (AI) can be used to help establish a digital, networked monitoring and supervisory system and a big data management platform with monitoring information of each management node concerning water supply, use and discharge connected. Additionally, an integrated digital system that can realize the comprehensive objectives of regional flood and drought prediction and early warning, water allocation, water environment improvement and aquatic ecosystem conservation is required to be established to dispatch and manage regional water resources in a refined and scientific manner. This will not only provide Yunnan with essential practical experience for its future construction and operation of province-wide water supply network, but lay a foundation for building the big data platform of water conservancy, agriculture and environmental protection and the complex of professional and systematic application and management. Water conservancy in Yunnan will fundamentally transform from “traditional” to “digital” and to “smart”, helping modernize the integrated management of water resources.

5. Conclusions
In Yunnan Province, dam regions (basins and river valleys) that are suitable for industrialization and urbanization only account for 6% of its total area due to the complex terrain, while water resources are difficult to access despite their abundance. In particular, central Yunnan, which is of great significance to the coordinated development of the province’s economy and the important growth poles, has to run 70% of the Yunnan’s economy with only 15% of its water resources. To resolve this acute imbalance between water supply and demand, it is essential to gradually prioritize water conservation and realize spatial water balance, and vigorously address the shortage of water conservancy infrastructure. More importantly, it is necessary to improve monitoring capacity and management of water resources by constantly establishing and perfecting systematic management and coordination between the market and government. Hopefully, this paper will help key areas of Yunnan Province represented by Kunming, Qujing, Dali and Yuxi to accelerate their research on specific issues, for instance, “intensive management of regional water dispatch”. It will also promote the construction of demonstration zones of integrated water management featuring digitization and informatization with large and medium-sized projects as pilot programs, such as “seven reservoirs, one station and one river” in Dianchi Lake basin that supply water to important water sources, Qulu dam region in Qujing City, and Chemabi Reservoir. These steps have great practical significance, which will help accumulate abundant experience that can be used by other regions in Yunnan Province and meanwhile lay a solid foundation for the optimal allocation, efficient utilization, accurate dispatch and information-based management of water resources in wider areas.

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