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Water delivery performance in the Maricopa-Stanfield Irrigation and Drainage District

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Abstract. A Diagnostic Analysis was conducted in the service area of the Maricopa-Stanfield Irrigation and Drainage District in Arizona, USA. The study was an initial step in a managed change process, named Management Improvement Program (MIP), aimed at improving the performance of the area's irrigated agricultural system. Part of the Diagnostic Analysis study focused on the performance of the irrigation district's water delivery service. The study identified areas of high and low water delivery performance, factors contributing to the observed levels of performance, and implications to on-farm water management. These findings prompted changes in the delivery system's management. Results from a post-MIP intervention study indicate that the district's water delivery performance has improved as a result of those changes, and thus, that the Diagnostic Analysis and MIP methodologies are effective tools for promoting positive change in a water delivery organization.

Key words: agricultural system, delivery system, management, performance assessment

Abbreviations: ASCE – American Society of Civil Engineers; BOD – Board of Directors; CAP – Central Arizona Project; DA – Diagnostic Analysis; MIP – Management Improvement Program; MSIDD – Maricopa-Stanfield Irrigation and Drainage District; USBR – U.S. Bureau of Reclamation

Introduction

In late 1990, the board of directors of the Maricopa-Stanfield Irrigation and Drainage District (MSIDD), Arizona, agreed to participate in a demonstration project of a process for improving management and performance of agriculture within the district's service area (Dedrick et al. 2000a). The process, named Management Improvement Program (MIP), assumes that long-term improvements in resource management and agricultural productivity require coordinated efforts by farmers, the irrigation district, governmental support and regulatory organizations, and other stakeholders in the agricultural area.

Therefore, the MIP seeks to involve these stakeholders in the identification of opportunities for improvement and in the joint planning and implementation of programs to address those opportunities. The demonstration MIP project was conducted over a three-year period beginning in 1991.

An expected outcome of the demonstration MIP was an understanding of water delivery performance in the area and potential improvement in on-farm water management through changes in the water delivery service to farms. Consequently, these issues were investigated as part of a field study, called Diagnostic Analysis (DA), that was conducted during the initial stage of the MIP. The DA characterized the performance of MSIDD as a water delivery organization and also of the overall agricultural system that it services (Dedrick et al. 2000b). The purpose of this paper is to describe the delivery performance and the actions that the district undertook in response to these findings.

Evaluation of water delivery system performance

Concepts and methodologies for assessing the performance of delivery systems have received significant attention in recent years and there are at least three perspectives that need to be considered in such studies:

- the degree to which the delivery organizations objectives and corresponding service meets the needs of water users;
- the impact of the delivery organization's environment on its definition of objectives and its ability to meet those objectives, and;
- the impact of the delivery organization's internal structure on its ability to meet its objectives.

These issues are explained in the following sections.

Needs of the water users

Farmers' water demand patterns are dictated by agronomic, weather, irrigation system, and farm management factors. The delivery system aims to satisfy those needs subject to the constraints imposed by the available water supplies, the conveyance infrastructure, user water rights, costs, and other delivery system environment factors. Delivery objectives and rules for distributing water are determined based on these constraints. The farmers' ability to manage water on the farm is affected by the flexibility of the delivery rules and the quality of service provided under those rules. Because water demand patterns vary throughout the irrigation season, an inflexible water delivery service, i.e., a service where delivery frequency, duration, and flow rate cannot be easily changed in response to changing circumstances, can result in water deficits and consequent crop water stress, or alternatively, in excessive irrigation with consequent waste and water logging problems. Even if the service is somewhat flexible, farmers can still have a difficult time managing water on-farm if the quality of the service is poor. The quality of service can be described in terms of performance parameters, such as adequacy, accuracy, timeliness, and equity (Molden & Gates 1990; Murray-Rust & Snellen 1993; Bos et al. 1994). Adequacy describes how well deliveries meet crop water demands over the service area, both over the season and at specific crop growth periods. Accuracy is commonly used to describe how well the expected and actual flow rates match. Timeliness is used to describe the relationship between expected and actual frequency of deliveries. Combined, accuracy and timeliness describe the reliability of the service. Equity refers to whether the water deliveries match the stated allocation for all users. Water quality (salinity, sediment load, and temperature) also determines the quality of the water service (Svendsen & Small 1990). In theory, greater service flexibility and quality should facilitate on-farm water management. In practice, the impact of irrigation delivery performance on water management on farm is difficult to assess because farmers' irrigation strategies depend on other factors besides the delivery service's characteristics.

Operating environment

The delivery organization's environment consists of the economic and institutional framework under which it operates. As was explained above, this environment imposes constraints on the delivery service. The delivery organization's long-term organizational objectives, strategies, and delivery rules are determined based on these constraints. Part of the economic environment is the set of physical resources available to the delivery organization, including water, capital, power, labor, and infrastructure. Infrastructure plays a key role in determining the flexibility and quality of the service because better water control is possible with more control structures and better coordination in the operation of those structures. Another part of the economic environment is the economic relationship between farms and the delivery organization. Given that farmers and the delivery organization have limited financial resources, the water service provided must be cost effective to both. This is particularly true in delivery system's that depend on water sales or farmer paid fees for its revenues. In these cases, it is clear that the delivery system cannot be financially sustainable unless farmers are also financially successful. Even in cases where the costs of water and delivery system operation are heavily subsidized, the ultimate economic benefits of irrigation to society as a whole must outweigh the costs if the system is to be sustainable.

The institutional environment consists of the rules and organizations, both formal and informal, that determine water delivery and use (Svendsen & Small 1990). This environment includes water rights, regulations on agricultural production, and other laws, governmental and nongovernmental organizations, traditions, and even personal relationships among individuals. System performance will be inadequate in situations where water rights and the roles and responsibilities of organizations or individuals affecting the delivery system's operation are poorly defined, or where those rights or responsibilities cannot be adequately enforced (Perry 1994).

Internal structure

The delivery organization's internal structure consists of the human resources and processes used to deliver water reliably, efficiently, and cost effectively. Management of the system involves a variety of tasks (determination of water demands, canal operation, maintenance, construction, etc.) and, therefore, the organization needs to be configured to provide those services. These tasks need to be carried out systematically, following well-defined operational procedures, and individuals or entire operational units need to be properly trained in those procedures. Furthermore, the work needs to be properly coordinated and monitoring processes need to be in place to assure that work orders are carried out as planned. As an example, routing water through the canal system requires many check gate operations. These check gate operations, which are generally carried out by more than one individual, need to be coordinated to prevent water shortages, spills, or even damage to the infrastructure. To this end, pertinent information (gate positions, water levels, and flows) must be communicated periodically to a command center, either by the operators, water users, or automated data acquisition systems, to check the system's state. If a problem is detected, then the command center needs to determine a corrective action and communicate this information back to field personnel and/or water users.

User water demands and the delivery system's operating environment are both dynamic. Therefore, the delivery organization must be able to adapt to changes in these external factors, either by changing its delivery rules, organizational structure, or operational procedures. Feedback mechanisms, both formal and informal, are needed to obtain timely input from clients, the external environment, and organizational members, and to develop appropriate and timely responses to changing circumstances.

Diagnostic Analysis and delivery system evaluation

Diagnostic Analysis (DA) is a methodology for assessing the performance of irrigated agricultural systems. Its objective is to provide a foundation upon which collaborative planning and implementation activities can be carried out by agricultural system stakeholders (Clyma & Lowdermilk 1988). Two characteristics of the DA contribute toward this objective. First, the DA attempts to develop an integrated view of the agricultural system. This is done by analyzing the role played by the various individual components (farms, delivery system, regional economic system, support and regulatory government organizations, etc.) and by examining the interactions between these components. An interdisciplinary team is responsible for developing this integrated view. Second, the DA approach is based on action research principles – it seeks to promote change in a social group, the agricultural system stakeholders, by first obtaining data from the group, feeding back that data to the group, and guiding the development of a common understanding of the data by the group. Close collaboration between researchers and stakeholders is needed to reach the level of understanding needed to promote sustainable change.

Because of its key role in the agricultural system, a major focus of the DA is analyzing the delivery system's performance and to identify opportunities for improving the system's management. Hence, the performance of the MSIDD as a delivery organization was examined from the above described perspectives.

MSIDD delivery system diagnostic analysis

MSIDD is located south of Phoenix, AZ and construction of its facilities was completed in 1989. The infrastructure consists of over 362 km of concrete-lined canals and pipelines and related control structures, 180 turnouts, and nearly 400 irrigation wells. It services about 35,000 ha. MSIDD is a conjunctive use district and manages both surface water and groundwater supplies. Surface water is provided by the Central Arizona Project (CAP). The amount of groundwater available to individual farms is based on a grandfathered right set through Arizona Groundwater Management Act of 1980. In 1991, the district had a contract for a 22.75% of the CAP water available to non-Indian agricultural water users. Additional details on water rights and regulations affecting the district's supplies are explained in Wilson & Gibson (2000) and Wilson (1992). The district's staff in 1991 included 10 people in administration and 35 in operations and maintenance.

MSIDD is an arranged delivery system and farmers pay for water volumetrically. Deliveries to farm turnouts are monitored using ultrasonic flow meters which measure the flow rate at 15 minute intervals and also totalize the delivered volume. Deliveries from district-owned on-farm wells are also measured. Each turnout serves about 243 ha and can provide discharges of up to 0.43 m^3/s. Farms in the area are generally large so turnouts are normally not shared between farms. In cases where they are, district personnel use portable flumes to measure the split flow. For further details of the delivery system, the reader is referred to Dedrick et al. (2000a) and Dedrick et al. (1992).

The MSIDD DA research approach is described in detail in Dedrick et al. (2000b) so only a brief summary is provided here. Management and performance of the delivery system were assessed primarily through individual open-ended interviews of district personnel and farmers. Thirty of the 45 district staff members, including a sample of canal operators and all upper managers, were interviewed. Also interviewed were all nine members of the Board of Directors. The farmer sample was selected from farmers growing primarily cotton, the main crop in the area, and using surface irrigation, the main irrigation method. Of 47 such farmers, 25 were interviewed. It is important to observe that the DA findings are not based on field measurements of turnout deliveries or of irrigation performance at the farm level. While desirable, such quantitative performance measures would have required a far more extensive and costly research effort. Hence, it was assumed that indicators of system performance could be derived from farmer and district personnel impressions and, more importantly, that these qualitative assessments would help identify opportunities for improving system management.

MSIDD diagnostic analysis findings

DA Team interdisciplinary performance assessment

The DA Team prepared a report summarizing their findings (Dedrick et al. 1992), which included a series of statements describing the performance of the MSIDD agricultural system. The findings were grouped in three broad performance areas, namely economic viability, management, and technology upgrading (see Table 1). The performance statements listed in the table are those that are relevant to the water delivery service and its interface with farms. These statements were developed through the DA Team's interdisciplinary interpretation of the available data. The statements are not necessarily specific to particular professional discipline (see for example T1 in Table 1). Furthermore, many of these statements are somewhat generic and could apply to other irrigation districts (El). The following discussion attempts to consolidate some of these findings. Moreover, the discussion deals mostly with management and technology issues and less space is dedicated to the delivery economics and on-farm irrigation impacts. These aspects are covered in greater detail in Wilson & Gibson (2000) and Clemmens et al. (2000).

District objectives and overall attainment of those objectives

MSIDD was created with the objective of supplying local farmers with renewable water resources from the CAP and thereby reduce their dependence on limited groundwater. The system was designed to provide both high conveyance efficiency and high water control capability. Furthermore, the design specified a high turnout delivery rate, 0.43 m^3/s, to enable the adoption of modern irrigation technologies and facilitate farmers' on-farm irrigation practices. Some farmers in the area, in fact, adopted level basin irrigation technology on parts of their farms prior to delivery system construction. Construction of the system came at a high cost to the farmers, which was financed through federal and private loans, and the resulting cost of water was also high, $\$36/10^3\ m^3$. Therefore, in 1991, the district's objective was to provide a high level of service (high flow rates, accurate and flexible deliveries), meet groundwater regulations in the area, and at the same time trying to keep the costs of delivered water as low as possible.

The DA Team found that while the district was providing a reasonable level of service, delivery performance was below potential. Moreover, the cost of water was relatively high and groundwater use was increasing due to its lower cost relative to CAP water. These various issues are discussed in later sections.

Water delivery rules and performance

Delivery rules

MSIDD is an arranged delivery system. Farmers order delivery changes one day in advance and they can specify duration and flow rate. District personnel service those orders during a standard 8 hour work day, from 7:00 AM to 3:00 PM. Because of the time needed for the water to travel down the canal, the effective service window for farmers at the end of a long lateral is less than 8 hours. In 1991, delivery changes outside this standard window incurred a $100 fee. Check gate and turnout structures are operated by district staff. For farmers with on-farm wells, farmers must request the district for pumps to be turned on but they are able to turn the pumps off at will.

The delivery policy for the standard service window, which was adopted in consideration of the trade-offs between service flexibility and operating costs, creates service inequities. In particular, it affects farmers at the end of long laterals who have a shorter effective window because of the water travel time. In recognition of these inequities, District staff began modifying rules

Table 1. Diagnostic Analysis Report performance statements.

Performance area	Code	Performance statement
Economic viability of the irrigated agricultural system	E1	The current level of water costs and assessments, combined with yield and price variability, creates uncertainty in net returns for farm operations.
	E2	Management is using groundwater to stabilize water costs to the grower.
	E3	MSIDD's variable non-water costs represent a significant percentage of the net unit cost of water to the grower.
Management of the farm enterprise and MSIDD	M1	The quantity, quality, and dependability of water delivery has generated a positive production environment for water users in the district; however, current overall system performance may be lower than system potential, and some delivery procedures difficult to sustain.
	M2	Because of the standard water delivery service window (on and off), the flexibility and timing of water delivery service vary within the district; this influences farm irrigation operations, management practices, and investment in technologies.
	M3	Some MSIDD operational rules that might improve delivery service to many growers are neither widely known nor used; some growers are uncertain about other rules that appear to have been developed for particular situations.
	M4	The ability of MSIDD operating staff to deliver the requested flow rate and maintain it over time without significant fluctuation varies within the district.
	M5	While the growers and the MSIDD Board, management, and employees are quick to praise their working relationships and communication, there are specific areas where these processes could be strengthened.
Technology upgrading and new technology adoption by the farm enterprises and MSIDD	T1	Though MSIDD's ultrasonic flow meters are effective for water accounting and billing purposes and for operational management if properly used, they are rarely used by growers as management tools, and in general it appears they could be more effectively used by MSIDD personnel.
	T2	The intended transfer of remotely monitored and operated control (supervisory control) and its operational management procedures was not accomplished as planned, and as a result, the interim manual control procedures were continued, and further developed.

or developing new ones to meet special situations, but they did not attempt to systematically inform farmers about these rules. In 1991, District operational staff and management were still familiarizing themselves with the capabilities of the delivery system and therefore, management was concerned that they would not be able to support the modified or new procedures in the long run or if implemented district-wide. As a result, not all farmers in the District were utilizing the available operational flexibility.

For example, some growers in the sample said they were unaware of district rules such as the "will-call shut-off" and "minor change" orders. The first rule allows farmers to schedule a shut-off for the following day, without specifying the time. The farmer can then call the district the next day with a specific time (subject to the constraint of the standard service window). The second allows farmers to request a 25% flow change on short notice. This type of flexibility is possible thanks to the large storage volume in the delivery system's main canals. Also, on any given day, short notice requests can be honored if the requested flow increase (decrease) can be matched with a corresponding flow decrease (increase) on the same lateral. These rules provide greater flexibility to farmers in matching the end time of a delivery with the end time of an irrigation set. Most of those growers who were aware of these policies reported learning about them from a neighbor or one-on-one from district staff. As a result of this lack of information, some growers were investing additional labor and management to overcome the formal delivery rules constraints, with some reporting even altering their level basin designs. Further, farmers who knew about those services were uncertain that such services would be available in the future. Because on-farm irrigation strategies depend on the range of delivery services available, this uncertainty can influence seasonal irrigation strategic decisions. Lastly, services that are not widely known by the farmer population can create a perception of favoritism in the delivery service.

Flexibility and quality of the delivery service

Table 2 summarizes the responses of farmers to questions related to the flexibility and quality of the water delivery service. With few exceptions, the service was reported as being adequate in terms of satisfying user seasonal and daily water demands (question 1 in Table 2). In fact, as noted in Wilson and Gibson (2000), a problem confronted by the district was that seasonal water demands in the area were declining relative to its CAP allocation as a result of reductions in the area under cultivation. Therefore, the fixed delivery service costs were being spread over a smaller volume of delivered water. On the other hand, daily demands were greater than canal capacity on many days during the very hot 1990 season on the longer lateral canals. To mitigate

Table 2. Farmers assessments of MSIDD's delivery service.

Number	Question	Yes (%)	No (%)
1	MSIDD water delivery has produced periods of crop stress/yield loss	13	88
2	Water management flexibility has increased	74	26
3	Farmer considers the 7-3 window a problem	48	52
4	Farmer finishes irrigation outside the standard window	70	30
5	The delivered rate is the same as ordered	50	50
6	The flow rate delivered causes a problem	24	76
7	Fluctuations in flow rate occur	76	24
8	Fluctuations in flow rate cause a problem	48	52
9	Water delivery service is equitable	85	15

the impact, the district reduced the turnout flow rates to all users. While in principle an equitable measure, the curtailment had a greater negative effect on level basins. These system, which were designed for a 0.43 m'/s inflow, were provided with about 0.26 m^3/s resulting in a slower spreading of the water and less uniform and efficient irrigations.

Farmers' responses indicate that flexibility of the service varied within the district (questions 2–4). Nearly 75% of the interviewed farmers felt that their on-farm water management flexibility had increased over the previous years, when they depended only on groundwater. At the same time, half of the farmers stated that the standard service window restricted their management. The service window was a constraint these farmers had not dealt with in the past when they managed their own pumps. This apparent contradiction is explained by increases in delivery flow rates that were possible with surface CAP water. Because most farmers use surface irrigation systems, higher flow rates allow them to complete an irrigation more quickly or cover a larger area in the same amount of time. Farmers most affected by the delivery window were those located at the end of long laterals, due to the time required for the flow changes to travel to those distant locations, and those without on-farm wells (see Clemmens et al. 2000). Farmers with access to wells were often ordering canal water to he shut off during the regular service hours and completing an irrigation with well water, which they could then shut off at any time. Overall, it appeared that the district's 24-hour advance order policy combined with high flow rates was providing equal or better flexibility to most interviewed farmers than before the district's construction.

According to farmers, accuracy of deliveries also varied within the district (questions 5–8). This assessment reflects both differences in the quality of the service and in farmers' delivery needs as well as the farmers' past experience with pump deliveries. While half of the interviewed farmers said that delivery flow rate differed from what was ordered, less than 25% considered it a problem, probably meaning that the difference was small enough for practical purposes. On the other hand, 75% of the farmers experienced problems with flow fluctuations and nearly half of them considered fluctuations to cause on-farm irrigation management problems. Just as with flexibility, farmers whose turnout was located near the downstream end of a lateral canal and with level basin irrigation systems were more likely to be dissatisfied with the accuracy of the deliveries (see Clemmens et al. 2000). Thus, downstream turnouts experienced more significant flow fluctuations. It is unclear from the data, however, whether the dissatisfaction was the result of decreased performance of the on-farm irrigation systems or to more management and labor being needed to offset the effect of the variable deliveries. In any event, the responses do indicate management problems resulting from inaccurate deliveries.

Insufficient information was collected to characterize the timeliness of delivery service but the available data did not suggest systematic problems. Some incidents of forgotten or lost orders (usually for the special services turnoff – 3 pm to 7 am – that were made well in advance) appeared to be an artifact of the informal posting of such orders on "stick-tabs" for the appropriate future shift workers. These notes appear to be vulnerable to occasional loss, overlooking, or failed communications. On the other hand, operators reported instances of deliveries that could not be completed because farmers forgot they had ordered such deliveries. The district has a policy not to deliver water to a turnout unless the farmer or his irrigator is present to take control of the water. In cases where the irrigator fails to show up, and because the system was designed not to spill, the operator has to rapidly cut back the flow into the lateral to prevent damage to the farm conveyance system or the lateral itself.

Overall, a majority of the district's farmers perceived the delivery service as equitable (question 9). This suggests that while farmers may experience differences in service, they recognized that the delivery system imposes physical limitations that are difficult to overcome.

MSIDD's economic and institutional environment

Economic environment

The high cost of water delivered by MSIDD, approximately \$36/10^3 m^3 in 1991, was one of several factors contributing to uncertain economic conditions in the district area (E1, Table 1). In addition to the price of water, district farmers were also paying a tax (land assessment) to cover the delivery system's construction cost. This assessment varied within the district between \$50 and \$120/ha/year. Economic conditions were projected to deteriorate further by 1993, when the district was supposed to take all the water that it was entitled to by contract or pay a fixed amount for the unused volume. Since the district was already reducing its use of CAP water, due to cost, and since farmed surface was declining in the district, this meant that the district would not be able to meet its financial obligations and would have to declare bankruptcy.

The District's management and Board of Directors were aware of the impending crisis and were taking measures to reduce costs. Variable costs were being reduced by reducing the proportion of the more expensive CAP water in its mix and increasing groundwater use: in 1989, nearly 60% of the delivered water had been surface water and 40% groundwater and by 1991 those percentages had reversed. On the average, farmers in the district were still able to meet groundwater regulations because of the land that was not being farmed. At the same time, the district was seeking to restructure its debt as a means for reducing its fixed costs. Still, the DA Team identified opportunities for reducing operational costs while maintaining the quality of service through the implementation of supervisory control (discussed later). Also, the DA Team also found that the flexibility restrictions caused by the service window were affecting farmers unequally, and improved flexibility could result in improved on-farm irrigation performance and profitability. Further, it became clear that the cost of water and other financial conditions were preventing farmers from practicing crop rotation. Lack of rotation was suspected of being a factor accounting for declining cotton productivity, which in turn was contributing to reduced profitability of the agricultural enterprises in the area, and to the declining cultivated area. Thus, it was necessary for the district to find ways to encourage increases in crop area to boost farmer profitability, increase water sales, reduce variable costs, and ultimately strengthen its own economic viability. The reader is referred to Wilson and Gibson (2000) for a detailed description of the adverse economic environment confronted by MSIDD-area and CAP agriculture.

Farmer participation in district management

MSIDD is a farmer-controlled organization and is governed by a nine-member Board of Directors (BOD). The district is divided into three divisions, with three members representing each division. One member in each division is elected every year. In 1991, eight of the board members were district farmers and the ninth a local developer. In principle, all district farmers can play an active role in determining district policies as BOD meeting agendas have to be posted publicly and meetings are open. Development of sound policies requires effective communication mechanisms among the general farmer population, the BOD, and district management.

Interview data indicated that mechanisms by which board members and farmers communicated were mostly informal, overly dependent on the proactivity of particular BOD members and growers, and not on systematic efforts of the BOD to obtain farmer input. BOD members indicated that farmer attendance to meetings occurred mostly when an individual had a particular problem to address, but not to obtain general information or provide input on policy developments. From their perspective, farmers had elected them to deal with policy issues.

While comments by farmers suggested a generally good relationship between them and the district's BOD, management, and operational staff, some farmers complained of communication problems. Also, responses from farmers and district management indicated that mechanisms by which district management shared information with the growers and obtained their timely and relevant input had sometimes been inadequate. As an example, district efforts to obtain input from growers on such critical issues as water curtailment, delivery timing, and flow maintenance appeared to have been limited and may have contributed to policies and operating procedures that negatively affected some users or were misunderstood. The fact that a detailed description of the delivery rules had not been provided to the farmers in writing and that many farmers were unaware of rule flexibilities shows also that relevant policy information was not being clearly communicated to farmers. On the other hand, it appeared that because of the pressures of business and other interests, many growers did not attempt to communicate frequently with district staff and some felt that their opinion was not valued.

It is important to note that despite the perceived communication deficiencies between farmers and the BOD, most growers in the sample believed that the district was providing a reasonable service under difficult circumstances. Some growers had suggestions for service improvements and even those who were affected by an occasional problem remained supportive of district operations overall.

District relations with external organizations

The Diagnostic Analysis report did not examine in great detail the effectiveness of working relationships between the district and governmental organizations operating in the area. Water use in the MSIDD area is regulated both by national and state laws, and while many of these regulations apply to the individual farmers, the district assumes much of the responsibility for filing the necessary paperwork and is responsible for assessing the required charges.[1] The cost and paperwork generated by these requirements can be expected to create occasional frictions between the district and the regulatory agencies. Observations made by the authors of this paper and statements made by district farmers and personnel, suggest that there was significant lack of trust among these entities at the time that the DA was conducted. This lack of trust, which explains the initial refusal by district representatives to participate in the MIP (and the refusal by other districts who were also invited to participate), is best summarized by their initial reaction to the MIP offer: “Why would we want to work with these agencies that make our life miserable?”

District internal organization

Water control system

The district’s delivery system was designed and constructed for remote monitoring and operation of gates (remote supervisory control) on the main and lateral canals. The system was put into operation before the contracts for installing the supervisory control system were issued. Thus, the district was forced to start operation under manual control. Since manual operation was not planned, the engineering firm that designed the system did not prepare written management procedures for manual operation of the main canal. Similarly, the U.S. Bureau of Reclamation (USBR), who provided technical oversight to the project, neither provided nor required transfer mechanisms for operational management of the lateral canals. District personnel developed manual procedures with informal technical support provided by the designers. When the supervisory control system was finally installed, in 1989, it was not precise enough for the district’s desired degree of water control. Lack of accurate positioning deterred the district from adopting supervisory control and, thus, they continued to operate manually. Attempts to use automatic downstream level control failed, at least partially due to inaccurate gate positioning. In view of the high costs already incurred and the skepticism that had developed among BOD members concerning the reliability of the technology, District management decided to continue their efforts to pursue the development of supervisory control using primarily their internal technical resources.

The level of service flexibility and accuracy expected of a system such as MSIDD's requires numerous daily changes to the main and lateral canals' check structures. If done manually, this requires numerous trips by operators up and down the canals. The District was making significant efforts to provide a high quality service, as is suggested by the fact that it was using eight more operators than planned by the engineering consultant (the consultant estimated that 10 operators would be needed with supervisory control) and that these individuals were making numerous trips along the main canal (an average of 4. 3 round trips per operator was estimated based on the fuel consumption records). In view of the technical difficulties encountered, district operational staff had developed some skepticism about remote canal operation and feared it would degrade delivery service relative to their manual approach. Still, it is likely that a properly operating supervisory control system could provide similar if not better control with less effort. Subsequent implementation of the control system later in the summer of 1991 proved this to be true.

Water measurement

During startup, the district experienced acute problems with sediment accumulation in the pipes upstream from the turnout meters and a higher than acceptable meter failure rate. During this period, the district sought appropriate technical support to correct those problems. By the time of the DA, sediment problems had been eliminated in all but a few locations and failure rate had been reduced substantially, although failures still resulted from sensor defects, mechanical, electrical, or battery problems. Overall, the flow meters were proving effective for water accounting and billing purposes, as is demonstrated by the fact that the difference between the measured inflows and outflows were less than 2% in 1991, after accounting for seepage and evaporation. However, the DA Team detected a continued distrust of the meters by staff and farmers.

A sample of meter readings revealed differences among the meters in the accuracy and repeatability of instantaneous flow rate measurements. As shown in Table 3, some installations were yielding relatively precise readings while other were not. These variations in flow rate readouts were attributed to complex entrance hydraulics at many installation sites and the fact that these single-path ultrasonic flow meters did not sample a sufficient fraction of the flow area (e.g., whether the pipe is straight or has a bend, whether there is a gate constricting flow at the inlet to the pipe, etc.). The meter takes 96 readings per day, at 15 minute intervals, and since the meter errors were shown to be random, the daily accumulation of volume is very accurate. An accurate measurement can be obtained by averaging about 10 meter readings

Table 3. Sample of ultrasonic meter readings (m^3s).

Meter ID	E9-2	E7-3	E7-A1	E7-5
Condition	23 m of Pipe & gate	12 m of Pipe & gate	40 m of Pipe & gate	12 m of Pipe & gate
	0.190	0.085	0.337	0.142
	0.195	0.108	0.328	0.139
	0.187	0.096	0.337	0.144
	0.178	0.068	0.334	0.136
	0.201	0.099	0.331	0.139
		0.057		
		0.076		
Average	0.190	0.085	0.334	0.139
Standard deviation	0.009	0.0018	0.004	0.003
Coefficient of variation	5%	21%	1%	2%

over a relatively short time period. However, this depletes the batteries that powers the unit, and may lead to meter failure; hence, multiple readings are not commonly taken. Instead, operators were taking 5 readings, ignoring the high and low values, and averaging the middle three. This approach was providing reasonable flow rate estimates for most sites but inaccurate results at sites with a high amount of variability.

Besides the technical problems, the DA Team found that some of the operators were confused about the operational limitations of the ultrasonic meters, and were interpreting the current reading as the average over the previous 15 minutes. Because of this improper meter use, canal operators were investing additional time and effort to properly set the requested discharge at turnouts. Farmers were also found who had a similar incorrect interpretation of the meter readings. It is likely that some of the frustration and distrust of operators expressed by farmers, as a result of delivery flow rates not usually matching the requested flow rate, were caused by metering inaccuracies and misinterpretation of the meter readouts.

Operational procedures

When MSIDD started operations, they did not have personnel experienced with operational concepts appropriate to their particular delivery system, and in the case of some lateral operators, no experience at all with canal operations. Manual operation was demonstrated by the engineering consultant, including canal gate rating charts or tables, as a temporary expedient, but as was stated before, no written manual plan was provided. The limited experience of the initial staff appears to have been such that they may not have been in a position to sort out questions to pose to the consultant, USBR or other technical source. From the other side, the consultant and the USBR appeared to have had difficultly in locating a technically trained audience in the initial staff group that could assimilate technical input and translate it accurately to operational procedures. This apparently unintentional distancing of the staff from technical input left a vacuum that allowed the current evolution of operational procedures.

As a result of the limited technical guidance, more-or-less individualized procedures evolved in their place. During the interviews, the DA Team noticed different levels of understanding of canal hydraulics among the canal operators. Furthermore, three methods of operation appeared to be in use, with one method appearing to predominate (Dedrick et al. 1992). The lack of formalized procedures may explain some of the reported variation in service from lateral to lateral.

Operator training

Besides the incompletely formalized operational procedures, the DA Team also noted uneven technical training and varying canal operator understanding of canal measurement and operations equipment. Under startup conditions, staff solved many of their own problems, and at times they addressed similar problems quite differently. New staff were being trained primarily through limited, successive assignments with experienced staff. In short, performance levels appeared to depend more on informal training and individual commitment and less on formal MSIDD procedures. Interviewed farmers noted that there were differences in service depending on the particular canal operator, with most problems occurring when relief or weekend operators were on duty.

Physical constraints

Water control in open-channels is inherently difficult as a result of wave dispersion effects and the relatively long time that it takes for flow changes to travel down the canal. Because the waves arrive gradually, balancing inflows with outflows is a time-consuming task. Physical characteristics of the canal can make this task even more difficult. It is generally recognized that canal pools with limited water storage (i.e., where most of the pool is not under backwater effects) are more difficult to regulate than pools with large storage. In MSIDD’s case, storage is significant in the main canal but not in the laterals. Nevertheless, the district has the capability of providing high levels of control because main canal and laterals are provided with numerous control structures. Still, these structures need to be operated precisely and frequently in order to provide a flexible and high quality service. As was noted before, it is difficult and costly to maintain stable water levels in a canal that is manually operated.

Besides the technical problems associated with canal hydraulics and flow measurement, canal operations are complicated by factors beyond the control of operators. Two common problems reported by operators were trash catching in front of turnouts and power outages. District turnouts are equipped with screens to prevent trash and tumbleweeds from getting caught inside the turnout pipes, however the screens sometimes get clogged thereby reducing delivery rates. Because operators were equipped with radio communications, these problems were usually addressed quickly once noticed. A more complicated problem is power outages. These outages occur mostly during the summertime, the time of highest demands, due to lightning strikes. These power outages interrupt the operation of source wells (wells pumping into canals) and cause sudden changes in lateral flow. Sudden loss of pump flows can cause significant flow fluctuations and require reregulation of a lateral. Also, since there is no telemetry at the wells to signal outages, timely response and adjustment by district staff is difficult.

Internal coordination, communications, and working relationships

Organizational structure

MSIDD's delivery procedures require careful attention to communication and coordination in water delivery operations. District staff keep track of all water orders received from farmers. These orders must be consolidated so that surface flows from CAP and pump schedules for the following day can then be determined. Each lateral operator needs to be provided with a list of orders so that he can then plan his operations to meet the scheduled demands. Similarly, operators on the main canal need to plan their operational activities based on the lateral demands. To ensure the system's proper operation, maintenance activities also need to be carried out systematically and operators need to respond rapidly to unexpected circumstances.

Interviews of district management and operational staff identified some problems in the management structure. District management appeared to have been aware of these problems prior to the DA, hence the DA findings helped to confirm and clarify some of the operational staff's frustrations around divisions of duties and lines of communication. One example was that some individuals with similar or common responsibility appeared to have different reporting channels, without formal mechanisms for supervisory coordination and problem solving. Another example was seen in the differing information provided to the DA Team by management and operational personnel as to procedures for routing and handling problems reported by growers. Operational personnel appeared to have authority for decisions about reporting information to supervisors other than their own, with a potential for needed actions to be lost. Dispatchers, who keep track and assemble the water orders, and canal operators, who implement them, need to interact regularly. However, they were reporting to different supervisors, thus increasing the daily communication and coordination difficulties. Communication and coordination appear to have been handled relatively informally and seemed to be effective, yet potential for misunderstandings and operational complications was apparent.

The DA Team also found that while district staff was open to suggestions for improvement, their perception of the possibilities for operational improvement was limited. Because the mechanisms for investigating both staff complaints and staff suggestions for system improvement appeared to not be clearly defined, staff was not providing systematic feedback on operational performance. At the same time, operational staff interviews suggested that actions taken and/or management responses were not always communicated effectively to the staff.

Employee growth and satisfaction

During the DA interviews, canal operators identified various difficulties in carrying out their tasks, some of which have been described in previous paragraphs. Despite these difficulties, most operators expressed a commitment to carrying out the district's objective or providing a high quality delivery service. This objective had led to explicit district management decisions for relatively intensive staffing by high quality, productive individuals. Further, the district was making efforts to retain those individuals by providing cost of living pay raises, of 4% in 1989 and 1990, and limited to 2½% in 1991 and by beginning an overall personnel policy review, including personnel structure, size, and compensation.

In general, canal operators expressed pride in being helpful to growers, appreciated the independence and responsibility of their work, and believed they were successful in providing a quality service. While the level of service offered by the district occasionally implies significant effort by the operators, only a fourth of the interviewed individuals felt growers had too much latitude in adjusting water orders. Almost without exception, canal and lateral operators expressed a desire to continue their jobs with the District for the foreseeable future, citing job challenges and satisfaction.

BOD-MSIDD management relationships

The role of the BOD and management in a typical U.S. irrigation district is described in ASCE Manual 57 (ASCE 1991). Broadly speaking, the BOD's role is to formulate objectives, strategies, and policies and approve budgets while management is responsible for planning, implementation, monitoring, and management of day-to-day operations. Interviews of BOD members and management staff revealed differences within the BOD, and between the BOD and management, in their interpretation of their roles and responsibilities. Thus, what some respondents viewed as policy-related input others viewed as operational interference. Complaints about BOD operational interference were validated by observations made by the DA Team during the course of the DA study. In one instance, a district field employee, who was performing a particular maintenance task, was reassigned by a BOD member to a different task. Besides the fact that the initial task had not been completed, the whereabouts of the employee was not known to his supervisor, who noticed his absence and was looking for him. The DA Team communicated their observations to those BOD members involved in the incidents. While the extent and significance of this inadequate role differentiation could not be assessed from the available data, it is clear that it can potentially weaken the internal communications and relationships between the BOD and management and dilute the BOD's contribution to problem solving and strategy formulation.

Communication and coordination with farmers

Good working relationships and effective communication between the district and its clients are key components of an adequate water delivery service. In general, communication difficulties seemed to have had relatively minor impacts on delivery with no reported incidents of problems that caused crop losses. Moreover, most growers noted significant improvement in service over the two years prior to the DA. While the goodwill generated had allowed growers and district personnel to work together constructively on specific problems in the past, isolated instances of unresolved grower concerns suggested a lack of understanding between the district and their clients with a potential for hurting what were otherwise positive working relationships. The key question is whether information provided by the district was appropriately focused and whether it was being communicated adequately among all concerned.

The farmers' uneven level of understanding of changes in delivery policies, and frustration with such changes, suggested weak communication mechanisms between them and district management. For example, and as was indicated earlier, some growers in the sample were unaware of some district practices (e.g., the “will call” shutoff alternative), while most who were aware indicated they learned of these practices one-on-one from another grower or the staff. In general, ad hoc policies, exceptions to standard operating procedures, or new or changed rules (many of which might result in more favorable delivery performance) appeared to be inadequately known, understood, or used by most growers.

Day-to-day communication among growers, dispatchers, and canal operators appeared to be good but with occasional problems, largely due to the apparent absence of a uniform policy on confirming and reconfirming start and stop orders. Most canal operators appeared to communicate with the grower as to when orders would be delivered, but others did not. Thus, as was discussed earlier, canal operators had at times failed to receive water orders while farmers had also sometime forgotten about changes they had ordered. When incidents occur during the day, usually the problems that follow are relatively minor; when they occur at night, the consequences are generally more serious. The less systematic noting of night changes and the method of communicating them to lateral operators appeared to be the major causes for missed changes.

DA and MIP impacts on water delivery performance

Because of its newness, MSIDD was not considered an ideal location for carrying out the demonstration MIP. The district was perceived as an effective delivery organization and no significant problems were immediately apparent to the MIP project leaders and sponsors. Still, the DA process uncovered opportunities for improving the district’s management. More importantly, the DA findings provided a foundation for changes that the district undertook in an effort to be more responsive to farmers’ needs.

A study was conducted in the fall of 1993 to evaluate the impacts of the demonstration MIP on the MSIDD-area agricultural system (Le Clere et al. 1994). Impacts on the district were examined in great detail as part of this study. Directly and indirectly, the DA findings and the subsequent MIP planning and implementation activities led to changes in the district’s water control procedures, in service policies, in organizational structure, in relationships with farmers, in relationships with governmental agencies, and lastly, in the district’s perception of its organizational mission. These findings are summarized next, focusing first on short-term changes that were directly influenced by the DA and, secondly, on medium and long term changes influenced by the overall MIP effort.

Short-term impacts

The district began to react to the initial DA findings while the study was still in progress. These impacts are reflected in changes in two specific elements of the district's internal organization, namely its management structure and in its water control and measurement approach.

Organizational structure
District management stated that early DA findings confirmed and clarified some perceived problems in their management structure. The management staff was restructured late in the summer of 1991, an additional foreman hired, and workload redefined and redistributed. Board, management, and operational staff members credited the organizational restructuring with alleviating communication problems between canal operators and their supervisors. The reorganization was also credited with freeing a staff member to resolve problems preventing use of the canal supervisory control system.

Prior to the DA, District management had occasional meetings with operational staff, their main purpose being, reportedly, to keep operators abreast of ongoing issues. After the reorganization, management instituted regular meetings to obtain more timely feedback from operators and to discuss specific issues affecting water delivery service.

Water control and measurement
The initial DA findings relative to water control provided further impetus to district personnel to solve problems related to the supervisory control system. District management credited a DA Team member with providing them with ideas about canal supervisory control. Following the reorganization, the district's watermaster devoted himself full time to get the system operational. Some technical difficulties were resolved shortly thereafter and the remote supervisory control system for the main canal was put in operation a few weeks later. This change had an immediate financial impact on the District, as part of the eight additional operators needed to operate the main canal were laid off while others were assigned to other duties.

In addition to identifying problems with the installation and operation of turnout flow meters, district management acknowledged that the DA findings increased their awareness of the importance of accurate water measurement. Deficient turnout meter installations were fixed shortly after they were identified and management made efforts to better train their operators and inform farmers on the correct operation of those meters. Furthermore, improvements were made to some lateral canal flumes. These flumes had not been properly installed and, as a result, were not yielding reliable readings and were not being used by operators to set the inflow at the lateral headings. It is likely that distrust of the flume measurements was also influenced by the turnout installation and operational problems (i.e., mismatch between the sum of turnout readings and the flume reading at the lateral heading).

Medium- and long-term impacts

Subsequent to the completion of the DA report, MSIDD management and several BOD members were involved in various MIP-initiated planning and implementation activities. Directly and indirectly, these activities led to changes in district policies and elements of its internal organization, in its institutional development, and ultimately on the quality of its water delivery service.

Policy and procedural improvements

Water ordering guidelines. In 1993, the district published for the first time a complete set guidelines for ordering water. Management acknowledged that this change was influenced by the recognized need to improve communications with growers, which was brought about by the DA findings and MIP activities. An interesting aspect of this effort to improve communications was that the guidelines were not distributed in a mailing but, rather, were handed out individually to farmers when visiting the district's office. Although at the time of the evaluation a general mailing of the guidelines to all MSIDD growers was still pending final edit, it was estimated that 75% of MSIDD growers had received the draft version. It seems likely that staff-grower exchanges incident to the District's efforts to inform growers about water ordering and delivery policies contributed to the improved grower understanding of system capabilities and constraints reported.

Winter water rates. At the time of the DA, high water costs and slim profit margins on winter grains (barley, wheat, and oats) were discouraging growers in the MSIDD area from planting these traditional rotation crops. The District was already providing lower water rates in winter, and in the 1991–92 winter growing season, the program was mildly successful. In a 1992 letter of notification to growers, management, citing the DA findings relative to the increasing trend toward a cotton monoculture, reduced rates even further ($27.60/$10^3$ m^3 in 1991–92, $20.30/$10^3$ m^3 in 1992–93) and made a more timely announcement of the program (August 24, 1992, vs. September 30, 1991). This internal subsidy, along with improving grain prices and credit conditions for production of small grains, encouraged MSIDD-area farmers to increase their small grains production in subsequent years (see Le Clere et al. 1994 and Dedrick et al. 2000 for more details on the impact of this program).

Internal organization

Organizational reorientation. MSIDD completed the construction of its canal system only two years prior to the MIP and, thus, was still a young and evolving organization in 1991. During the MIP years, 1991–93, the District was confronted with serious financial problems as a result of the take-or-pay provisions of its Central Arizona Project water contract with USBR and the Central Arizona Water Conservation District (Wilson and Gibson, 2000). Therefore, it is not surprising that the District underwent an organizational reorientation during this period. Comments by District managers and BOD members and observations by the authors indicate that the MIP contributed to this transition.

The District's General Manager played a significant role in the development of an interorganizational group that coordinated MIP activities subsequent to the completion of the formal MIP program, the Coordinating Group (discussed below). Based on this experience, the District's General Manager proposed to the BOD in the summer of 1993 the idea of participating in an organizational retreat. During this retreat, BOD members defined a mission statement for the District, which advocated, like the Coordinating Group's mission statement, the concepts of profitability, sustainability, grower-centeredness, and interorganizational collaboration. Both, management and BOD members, credited the MIP with broadening and helping them articulate more clearly their mission concept. While the ultimate consequences of this exercise are very difficult to quantify, operational staff and farmers have recognized the District's efforts to provide a higher level of service.

Individual professional development. Three of the District's upper manager were continuously involved in MIP activities and they all reported impacts from these activities on their attitudes or performance in work outside of MIP activities. The MIP process was credited with providing them with added skills in the areas of leadership, communication, and consensus building and with broadening their view of their professional responsibilities,

On the other hand, the BOD discouraged the District's manager from assuming a leadership role in the Coordinating Group, thus distancing itself from opportunity of playing a more active role in collaborative MIP activities.

Institutional environment

Relationships with external organizations. One of the purposes of the MIP was to strengthen relationships and communications among agencies that support and regulate irrigated agriculture in the area, including MSIDD. All board and management staff interviewed for the Evaluation Study reported significant improvements in relationships between the District and other organizations as a direct result of the MIP (Le Clere et al. 1994). This assessment was further supported by statements made by various agency representatives and by farmers receiving services or being regulated by these agencies. The change was largely an outgrowth of the planning and implementation activities undertaken by MSIDD representatives in collaboration with other organizations. A key example of this collaboration was the interagency Coordinating Group, which sponsored open-house type meetings, published a quarterly newsletter, and supported periodic meetings of a farmer-to-farmer discussion group from 1994 through 1996. While these formal collaborative activities have been discontinued, largely as a result of the departure of key players from the area, it is believed that they enhanced the District's image as a progressive organization and helped it to attract investment during the mid and late 1990's, a financially difficult period for CAP agriculture.

Water delivery service

Ultimately, the MIP process had a significant positive influence on the quality of the District's water delivery service. This was initially stated by farmers interviewed for the Evaluation Study (Le Clere et al. 1994), most of whom reported improvements in the flexibility and quality of the delivery service. Those who didn't report improvements were already satisfied with the service prior to the MIP intervention. Specifically, growers reported fewer problems with timeliness, fluctuations, and emergency situations. Physical changes in the system (e.g., supervisory control of the main canal, installation of measuring devices, modification of existing canals) as well as management and communication changes (e.g., greater operator experience with the system, reorganization of the District staff, dismissal of employees with poor performance records, greater cooperation of District staff) were mentioned by the farmers as reasons for the improved performance.

The Evaluation Study results also suggested that an important factor affecting farmers assessment of the service were changes in communications and working relations between growers and district staff, and a mutual understanding by farmer and district of each other's needs and constraints. The publication of water ordering guidelines was often mentioned as a factor contributing to improved communications. "It was the first time policies were in writing and were made clear," said one of the respondents. Other interviewed farmers noted that water dispatch employees were trying harder to accommodate their special demands than in the past, were making greater efforts to provide better information, and linked the attitude change to changes in communications and understanding. Finally, several respondents acknowledged the district's management increased efforts to seek their input.

There are indications that the District has not only continued to provide a high level of service but has made efforts to further increase that level of service. In late 1994, District BOD members identified the improvement in delivery service as the most significant impact of the MIP. More recently, district staff reported that nearly 50% of the water orders that they service on a given day are orders placed on the same day while the official policy requires farmers to place orders 24 hours in advance, which is an indicator of the high level of operational flexibility that the District has been able to attain.

Conclusions

Water delivery performance in the Maricopa-Stanfield Irrigation and Drainage District, Arizona, USA, was analyzed as part of a Diagnostic Analysis (DA) that was carried out in the district's service area. When the DA was conducted, the district had been delivering water for only four years. Therefore, the DA findings reflect the district's early evolution as a water delivery organization. Results indicate that the delivery flow rates were higher than those previously available in the area, when the farmers depended on groundwater supplies only. The increased discharges facilitated on-farm irrigation management. Also, the service appeared to be highly reliable and the district was investing significant effort and resources to provide a high quality service. Overall, farmers felt that improvements had been made over the district's short history of operations and were supportive of their operations.

Results also indicate that the district was not taking full advantage of its operational capabilities. The system was being operated manually even though it had been designed for remote supervisory control. While measurement devices were being effectively used for billing purposes, they were not being used adequately for managing operations. Delivery rules and policy changes were not well known or understood by all farmers, and the flexibility of the system was being underutilized. Also, lateral operators identified different channels for reporting complaints or problems. Hence, it appeared that communications among farmers, members of the Board of Directors (BOD), and district staff needed to be strengthened. These various issues were directly or indirectly impacting district delivery costs and on-farm irrigation management. In 1991, the agricultural economy of the region was in a precarious condition, and high water costs were threatening the economic viability of farmers and of the district itself. While the high cost of water was in large part related to the district's construction costs, it appeared that there were opportunities for reducing costs while maintaining a high level of service.

The DA process and subsequent planning activities helped district staff, BOD members, and farmers gain a better understanding of the impact of the water delivery service on farm irrigation management and profitability. Based on these findings, the district improved water control and measurement, changed its internal organization, improved communication of its rules and policies to farmers, and adopted an aggressive winter water rate policy to encourage crop rotation. The MIP also contributed to an improvement in relationships and communications between the district and government agencies that were previously viewed with a high degree of suspicion. Finally, the MIP activities led to a reassessment by management and the BOD of the district's organizational mission. It was therefore demonstrated that the DA and MIP methodologies are valuable tools for understanding delivery system performance and its impact on the irrigated agricultural system, and that this understanding can lead to management improvements.

Note

1. Water use in the MSIDD area is regulated both by national and state laws. The role of various of these governmental organizations is discussed in Wilson and Gibson (2000). While many of these regulations apply to individual farmers rather than to the district itself, the district assumes much of the responsibility for filing the necessary paperwork and is responsible for assessing the required charges. For example, the district's contract with the U.S. Bureau of Reclamation (USBR) for CAP water requires farmers to abide by the Reclamation Reform Act regulations. While farmers who do not meet these regulations are not entitled to CAP water, they still have to pay a fee for use of the delivery facilities, which adds to MSIDD's bookkeeping costs. MSIDD also has to report to the USBR the surface irrigated with CAP water, and to the Arizona Department of Water Resources the amount of groundwater used as well as the total amount of water used on individual farms.

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