Teaching canal hydraulics and control using a computer game or a scale model canal

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ABSTRACT

Irrigation is well known for being the largest water user, responsible for about 70% of the total amount of fresh water withdrawals. At the same time, this irrigation contributes for about 40% of the total food production and is vital for many regions of the world such as Western USA, Australia, Southern Europe, and many countries in Asia and Africa. Recent FAO figures indicate that, by the year 2030, food production will have to be increased by about 80% with only a possible increase of 12% of the water withdrawal. One unavoidable way of being able to reach this agenda is to reduce water demand by improving the hydraulic efficiency of irrigation schemes. Technical concepts involved in these modernization projects include open channel hydraulics and control engineering, which are usually taught in separate college curricula. Such projects are carried out in many places in the world, especially in developing countries, with the help of engineers, canal managers and decision makers. This paper presents two innovative teaching initiatives targeting this audience, with a view to present classical and modern techniques to improve the hydraulic efficiency of irrigation canals. One is based on a computer game using the SIC hydrodynamic model developed by Cemagref, France and the other one is based on a scaled canal located at the USBR Hydraulics Laboratory in Denver, Colorado, USA.

INTRODUCTION

Modernization of hydraulic regulation of irrigation canals is a proven method to increase the global hydraulic efficiency of irrigation projects, from below 40% for old traditional irrigation canals up to more than 90% for modern systems with automatic control algorithms. Modernization can also improve the quality of service to water users, allowing crop diversification and alternative field irrigation techniques, and can protect the infrastructure during emergencies such as heavy rainstorms or technical failures. Different surveys carried out in the USA, France, and Australia have confirmed the positive impact of irrigation project modernization and have promoted such projects.

Even though some irrigation canals have been operated for hundreds or thousands of years, available canal control methods have changed dramatically during the last few decades. The introduction of sensors, motorized gates, SCADA systems, and computers, combined with advances in hydraulics and control engineering, has allowed new automatic control techniques such as distant downstream controllers or centralized controllers. Even more classical local upstream controllers can be improved to become more efficient and flexible using digital technologies.

Most new large irrigation canals are now designed and built using modern technologies allowing advanced control procedures (Narmada Canal in India, South-North Water Transfer Canals in China, Toshka Canal in Egypt, etc). But more than 90% of the irrigation canals in the world are still using traditional technologies and simple manual operation principles. Reasons for this discrepancy are the lack of engineers skilled in this new domain and the reluctance of canal managers to change to an unfamiliar system with new technologies and new operation and maintenance procedures.

Some research and development institutes have built knowledge and experience in this specific domain of the regulation of irrigation canals, or more widely in the regulation of open channel hydraulic systems. This includes knowledge and experience in hydraulics, control engineering and adapted technologies. Cemagref in France and the Bureau of Reclamation in the USA are two of these institutes. Besides their research and consultant activities, these organizations build teaching packages that target students in civil, hydraulic or control engineering, canal managers and operators, and other professionals. These packages include computer games and hands-on activities on model canals. These methods have been used routinely for several years and will be described in the sections below.

INTERACTIVE COMPUTER GAME FOR CANAL OPERATION

Cemagref has designed an interactive computer game allowing students to manipulate several hydraulic gates in order to stabilize water levels in an irrigation canal following what is called a distant downstream regulation framework (Malaterre et al., 1998). This game is included in a larger teaching package spread over one to five days, depending on the school or audience. This game uses the SIC hydrodynamic software developed by Cemagref in Montpellier (Baume et al., 2005). It has been used for teaching sessions for at least three engineering schools (ENSEEIHT in Toulouse, AgroParisTech and SupAgro in Montpellier) with French and foreign students (to an average number of 15 to 20 graduate student engineers) and for canal managers of the Office du Niger in Mali. Previously, Cemagref organized similar capacity-building sessions in hydraulic modelling and canal regulation in Sri Lanka, Pakistan, Mexico, Mauritius Island, and Morocco.

When the class is organised in France, it includes a visit to the Gignac Canal with its centralized supervision and control system (Vion et al., 2007). Hands-on activities are also usually organized on the scaled canal of ENSEEIHT in Toulouse or SupAgro in Montpellier.

The course’s general objectives are to:

- Present the issues of operational management of open-channel hydraulic systems such as irrigation canals;
- Present a clear framework of solutions adapted to this issue;
- Show the problem complexity, in terms of hydraulic and control engineering aspects;
- Propose a way to model the system using a complete non-linear Saint-Venant model (SIC software) and simplified linear models (Transfer functions or State Space models);
- Provide technical background to design and analyze efficient automatic controllers;
- Evaluate and compare some of these controllers on the SIC simulation model;

- Show the differences and similarities with the small-scale canal by organizing a field visit of a real canal.

The course begins with a general presentation of the issue of operational management of open-channel irrigation canals. The operational objectives, constraints, and different control politics are presented.

Then, students perform manual control using the mathematical flow simulation model SIC, which solves Saint-Venant equations and enables interaction with users by the means of a standard pre-programmed regulation module called “STOP” (Malaterre et al., 2008). This experience is carried out as an interactive game where the students have to make decisions (gate operations whenever they want during the 12-hour scenario), can ask questions and have a final score that can be compared to other student classes and automatic controllers. The duration of the game is about 1½ hours. The canal to be controlled during this game is the canal 1 (Figure 1) of the Cemagref Benchmark (Baume et al., 1999). This is a 5-pool canal with a trapezoidal cross section (bed width = 7 m and bank slope = 1.5) and a longitudinal bed slope of 0.0001. Each pool is 3 km long and has an offtake at its downstream end. The initial hydraulic state is a steady state with 7 m^3/s head discharge and each offtake taking 175 l/s.

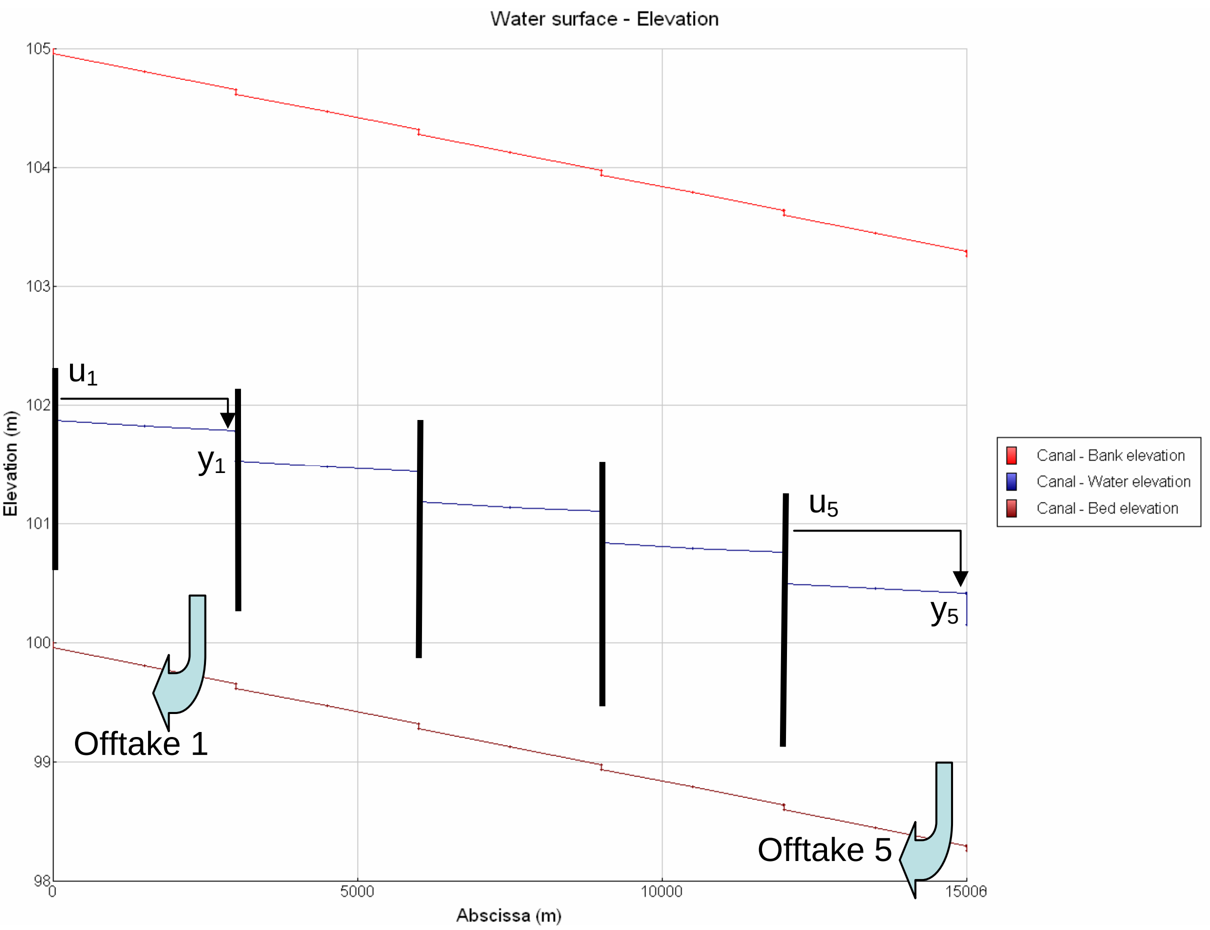

Figure 1. Schematic longitudinal view of the canal test

The student class is divided into five groups, each of them having the responsibility of managing one gated cross regulator in order to stabilize the water level at the downstream end of its downstream pool. The type of regulation we choose for this canal therefore belongs to the "distant downstream control" class (Malaterre et al., 1998), which is the more interesting but challenging one. Students do not know the timing or quantity of offtake changes in advance, which puts them in the same position as the manager of a canal functioning in an on-demand basis. The performance indicator used to evaluate students is the absolute sum of the maximum water level deviations around the targeted value (which is the initial steady state value) obtained at the five controlled locations. At the end of the game we observe the marks obtained, compare them to other controllers, and summarize the concepts that have been addressed and understood by the students during the game:

- *Concept of feedback* -- Students understand that by observing the deviation of the control variable relative to its target and by creating a corrective action, they can reduce its amplitude. We observe that (usually!) they obtain better results than if they had done nothing (see Figure 2).
- *Concept of feedforward* -- Students would like to know when the farmers take or stop to take water in order to anticipate their operations at cross regulators.
- *Concept of model* -- Students understand the importance of modeling the process at two different levels. The first model is a static model of the gate with the relationship between the gate opening and the local discharge. The second model is a dynamic model of the pool with the relationship between the upstream discharge and the downstream water level. Without these models, students have to find gate adjustments by trial and error procedures. When they ask for this type of information, we calculate approximate models using classical gate equations and theory of characteristics.
- *Concept of time lag* -- Students understand that it takes time for the control action to have an effect on the controlled variable located 3 km further downstream. Using the theory of characteristics, we calculate an approximate time lag of 15 minutes. Although some students have a tendency to check the water every 5 minutes at the beginning of the game, they learn they only need to check it every 15 minutes or more to be sure they can observe the effect of their control actions. Students also understand that this time lag is a main limiting factor for the performance they can achieve.
- *Concept of coupling* -- Students operating a given gate understand that the next downstream gate has a strong perturbing effect on the controlled water level, even though that is not its given objective. Therefore, they are very attentive to the downstream gate and take this information into account. They also understand that the upstream gate is also generating perturbation to their pool, but to a lesser extent.
- *Solidarity* -- Students understand that, due to coupling effects, over reaction can perturb other pools, especially the upstream pool. In most game sessions, in particular in those obtaining good overall results, students tend to smooth their actions so as to reduce side effects.
- *Concept of cascade control* -- Students understand that when one gate is operated to correct a deviation of the water level at the downstream end of its downstream pool, all the upstream gates should be operated in a similar manner.
- *Difference between upstream and downstream cross regulators* -- At the beginning of the game each student thinks he has the most difficult position, but by the end of the game students understand that the last downstream gate has a privileged position because no other downstream gate generates perturbations to it, and that the further upstream you go the more important are the perturbations since they sum up all downstream ones.

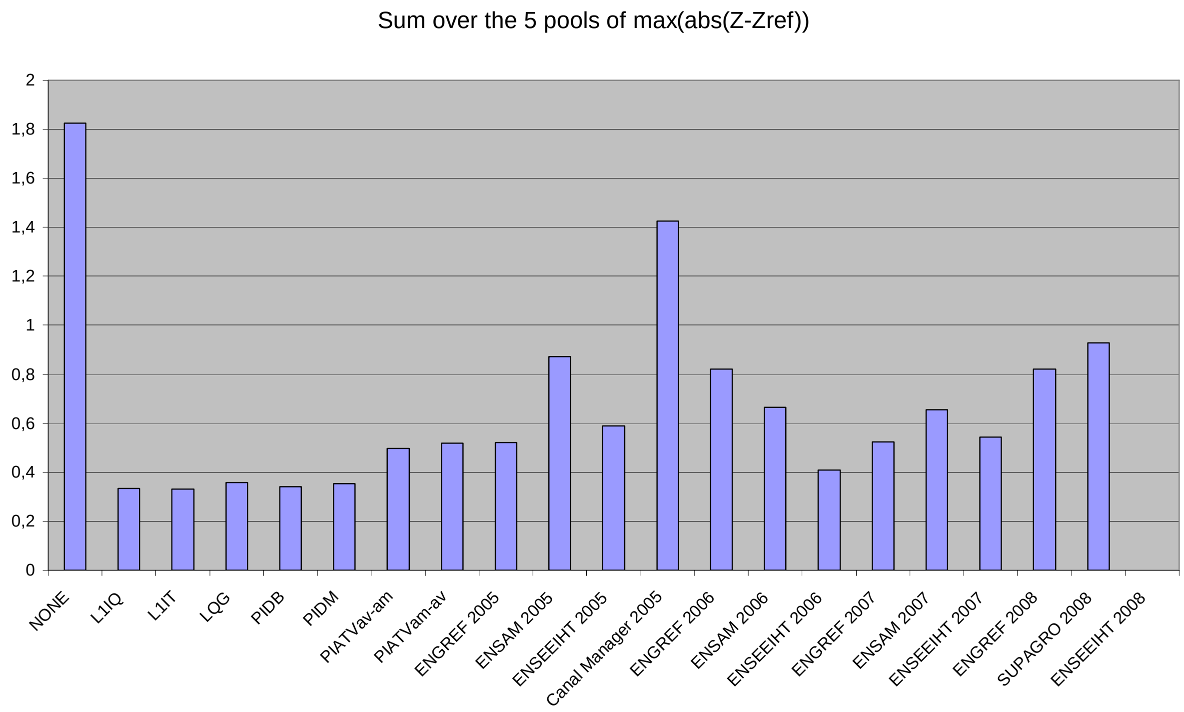

Figure 2. Results of the game for different student groups and automatic controllers (controlled variables)

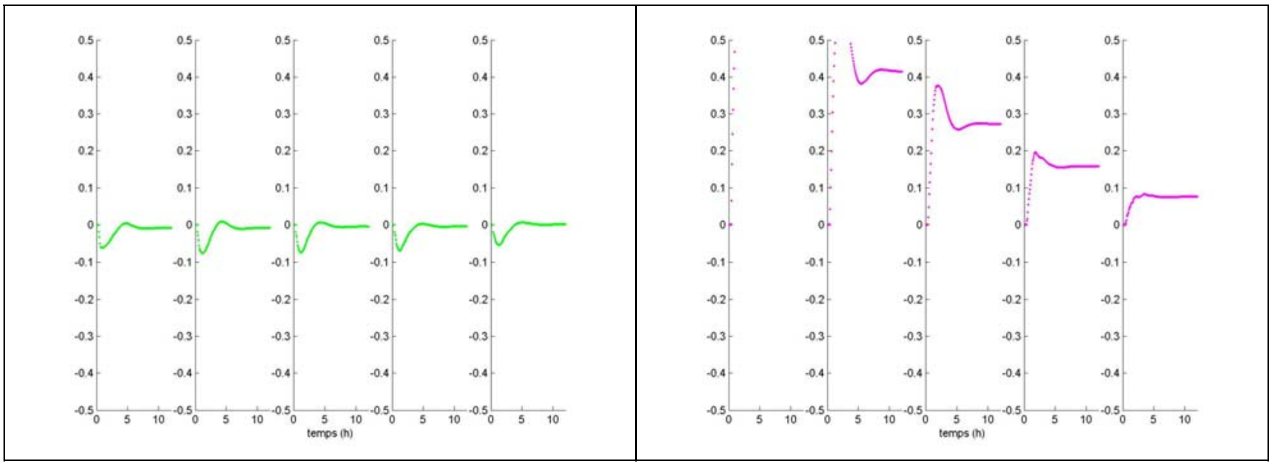

Figure 3. Water levels and gate positions for l1 automatic controller

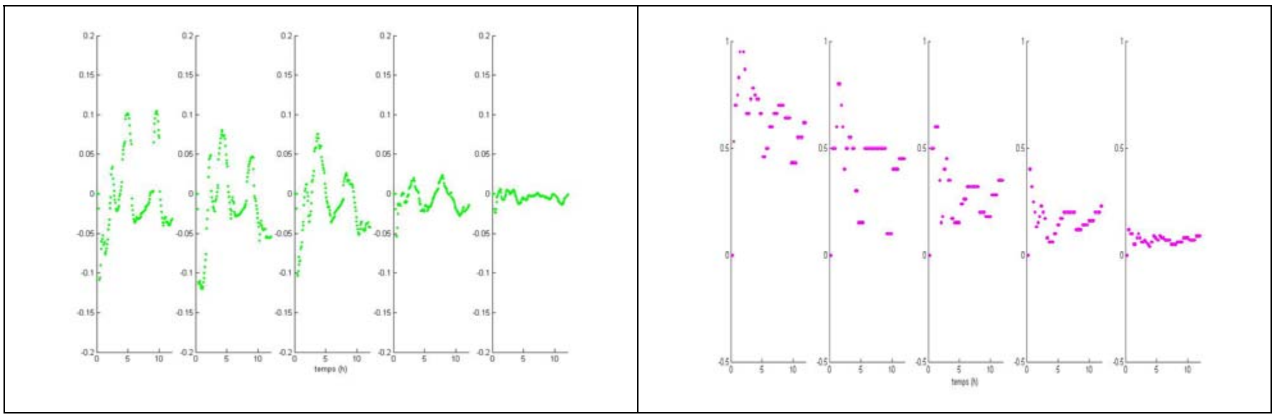

Figure 4. Water levels and gate positions for the game for Enseeiht 2006 students

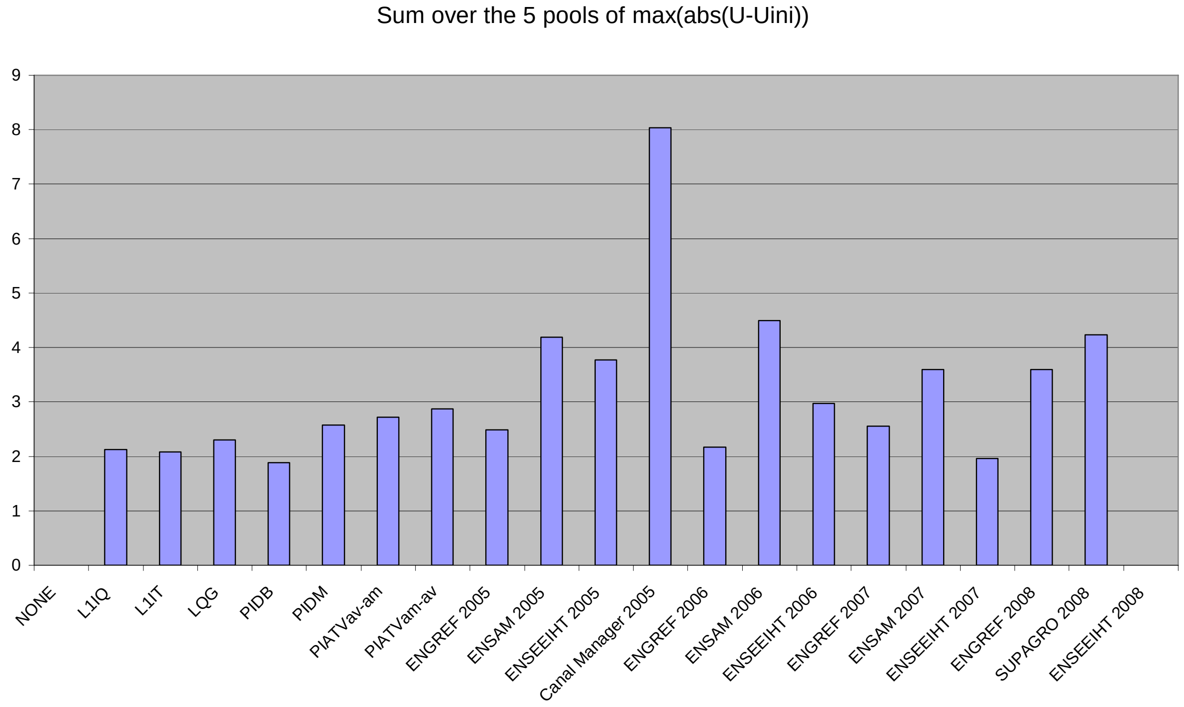

Figure 5. Results of the game for different student groups and automatic controllers (control actions)

Results obtained by students are compared to those obtained by several automatic controllers: two options of an l1 controller (Malaterre et al., 2003), a LQG controller (Malaterre, 1998), and two options of optimized PID controllers (Baume et al., 1999). We observe that all these automatic controllers get better results than all manual operations obtained by students. This is not so obvious since students have some advantages compared to these automatic controllers:

- Even though they do not know the scenario at the offtakes, they know this scenario is simple and they can guess what type of offtake perturbation is acting,
- Each gate keeper group has the knowledge of the operations of other gate keeper groups contrary to SISO controllers such as PID ones,
- Students can have a non-linear behaviour contrary to all tested controllers, which are linear ones.

Conversely, automatic controllers have several advantages compared to manual procedures of students, which explains how they can get better results:

- They have been designed (l1, LQG) or optimized (PID) using a model of the process,
- They make an adjustment every regulation time step (5 minutes) whereas the students tend to operate with a larger time step (5 to 15 minutes).

The good results obtained by these automatic controllers, even by the simple ones such as PID, is a good incentive for the students to understand the technical basis and tuning procedures for automatic controllers. These concepts are taught in the following class sessions when the teaching package is spread over several days such as for the ENSEEIHT Engineering School.

LABORATORY MODEL CANAL

Several years ago, the Bureau of Reclamation constructed a 100-meter-long model canal in its hydraulics laboratory in Denver, Colorado. This canal was designed for research, testing, demonstration, and training for canal modernization methods and instrumentation. The model canal is not a scaled replica of a real canal, but rather is a representation of typical irrigation canals with many different features used to demonstrate a wide variety of canal operating characteristics. The model is constructed from clear Plexiglas so the flowing water can be easily observed. There are five pools (reaches) separated by different types of controllable check structures (cross regulators), with four turnouts (offtakes). The source flow is a variable-speed pump. Data collection and monitoring is provided through a centralized SCADA (Supervisory Control and Data Acquisition) system that includes numerous water level sensors, gate position sensors, flow meters, remote gate control, and a communication system. Control options include local manual control at each check gate or supervisory control from a master control platform overlooking the canal. A photo of the model canal is shown in Figure 6.

Figure 6. Model canal in Reclamation's Hydraulics Laboratory

The model canal was designed specifically to provide training through "hands-on" workshops where students experience different canal operating techniques and control methods. For the past 12 years, Reclamation has hosted a 5-day course *Modern Methods of Canal Operation and Control*. The targeted audience for this course is canal operators, irrigation district managers, engineers, and other technical personnel who manage, operate, and design canal projects. Classes are held annually for participants from the USA, and an international class is organized about every 3 years.

The Modern Methods of Canal Operation and Control course covers the following topics, in a logical order from basic principles to modern technologies:

1. Basic canal hydraulics
2. Canal operating strategies and techniques
3. Control methods (manual vs. automatic; local vs. remote)
4. Flow measurement
5. Data collection instrumentation
6. Communication systems
7. SCADA hardware and software

The key to this course's success is not the subject matter, but rather how this subject matter is taught. In general, the students in these classes are experienced adults who work with operating canal systems and real-world issues. Most of them work outside and are not accustomed to sitting through long classroom lectures. Few of them have a formal education in science and engineering, so they have developed their knowledge of water project operations through experience “in the field”. These students learn much more effectively by first-hand experience than by listening to a technical explanation. Therefore, the course emphasizes learning via experience with a real (albeit small) canal and flowing water, where cause and effect are demonstrated with physical reality.

The course format includes many classroom sessions, so that academic topics can be introduced and discussed more easily with visual aids in a quiet environment. But these lecture and discussion sessions are both informal and relatively brief. After each topic is covered in the classroom, the students proceed immediately into a laboratory workshop where they can convince themselves whether theory and practice agree. Students will believe what they see with their own eyes and with real water, and then better understand the reasons for observed behaviour based on the classroom theory.

In basic terms, the training course teaches:

- How does water naturally behave, and why?
- What are the various operating techniques that can be used by canal operators to deliver water effectively and efficiently?
- What are the limitations and requirements for implementing these different techniques?
- How can these requirements be overcome with technological knowledge, tools, and instrumentation?

For example, one of the most basic and beneficial tools is flow measurement. Flow measurement allows canal operators to more easily understand and control a water delivery system. By measuring and balancing flows, operators can manage water volumes proactively instead of reacting to changes in water level and trying to correct problems. So flow measurement is a topic of emphasis, taught via classroom explanation of flow measurement devices and equations, followed by hands-on laboratory workshops. Figure 7 shows a smaller model used for flow measurement demonstrations and workshops. Using this small model and the larger canal model, students make their own measurements of dimensions and depths, then compute flow and compare the results using different methods. (See Figure 8.)

Figure 7. Portable model used for flow measurement and automatic control demonstrations

Figure 8. Flow measurement workshop

A series of workshops on the large model canal are effective to demonstrate different methods of canal operation. These workshops begin with “conventional” operations that are typical on most canal projects, wherein flow changes originate at the upstream end and migrate downstream via adjustments to in-line check gates. Although this conventional method of operation is practical with existing infrastructure, students experience its limitations to manage demand-based operations. Subsequent workshops demonstrate the increased capabilities of operating methods based on managing flows and volumes to better respond to downstream demands.

The model canal includes an extensive array of sensors, flow meters, gate actuators, data loggers, controllers, telemetry, and software. For example, the model is instrumented with dozens of water level sensors and gate position sensors, with many of the different types and brands that are typically used in the field. Students are able to see how these instruments are installed, calibrated, and used, including advantages and disadvantages of each type. (See Figure 9.) Because many of the students have experience with some of this instrumentation, both students and instructors learn from the personal experiences and preferences of others.

Figure 9. Demonstration of instrumentation and software used in SCADA systems

The culmination of the laboratory workshops is a friendly competition between teams of students. Called the “Canal Olympics”, this final workshop presents the students with a real control problem that combines scheduled deliveries and unscheduled changes. Teams are allowed to use any of the methods they’ve learned during the week in combination with the model canal’s control system, and develop their own operating strategy to manage the flow changes. Judging is based on effectiveness of meeting water deliveries while managing canal water levels and flows. This fun competition helps motivate students to learn as much as they can during the week, knowing that everything they learn will have immediate application.

CONCLUSION

Most canal operations personnel do not have formal training in open channel flow. Often, even the institutional knowledge from previous operators is not passed down very well to new staff, so they learn their trade on the job. Additionally, operators must devote most of their efforts to ensuring an adequate quantity of water delivery to customers, which doesn't allow much time or opportunity for innovation. Therefore, canal operator training can be of significant benefit it the training methods are effective.

The two methods presented in this paper are examples of effective training for people who learn better through experience than through a more formal classroom environment. These original teaching experiences mix open-channel hydraulics and automatic control, with an application to real-time control of flow in open-channels. Whether via Cemagref's computer game or Reclamation's model canal workshops, these methods succeed by involving the students with "hands-on" activities rather than passive listening. Both methods have the objective to train people in the domain of hydraulics and control for irrigation canals, hoping this will facilitate the introduction of new methods and technologies to operating projects.

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