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DESIGN OF IRRIGATION WATER SUPPLY SYSTEMS USING THE *Q–C* FEASIBILITY DOMAIN CONCEPT: I. INTRODUCTION AND THEORY[†]

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ABSTRACT

The *Q–C Feasibility Domain* (*QCFD*) was defined and proposed as a tool for design of multiquality irrigation water supply systems. It determines all feasible combinations of water discharge and water quality, and can be represented by a point, a line, or an area in a diagram of water discharge versus solute flow rate (a *Q–J* diagram). The shape of the *QCFD* is the result of dilution of two or more flows from sources of different water quality. (assuming conservative substances) Several types of *QCFD*s were analyzed at sources, inner nodes of a network, and of consumer outlets. The effect of water discharge constraints (due to flow limitations in the network) on the *QCFD*s was formulated and analyzed. Computation of *QCFD*s of dilution junctions by vector addition of their inflows was described. The method was extended numerically to nonlinear mixing due to dependence of water salinity. Use of this method enables computation of *QCFD*s for inner nodes in networks, including dilution junctions. The effect of network topology and flow direction was discussed. Application and demonstration will follow in the next paper in this series. Copyright © 2008 John Wiley & Sons, Ltd.

KEY WORDS: irrigation; water supply; water quality; irrigation systems; contamination network analysis; water discharge

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RÉSUMÉ

Le domaine de faisabilité Q–C (*QCFD*) a été défini et proposé comme un outil pour la conception des systèmes d'alimentation en eau d'irrigation de qualités multiples. Il détermine toutes les combinaisons faisables de débit et de qualité de l'eau, et peut être représenté par un point, une ligne, ou un secteur dans un diagramme débit-concentration (un diagramme de *Q–J*). La forme du *QCFD* est le résultat de la dilution de deux écoulements ou plus provenant de sources de qualité différente (en supposant la conservation des quantités). Plusieurs types de *QCFD* ont été analysés aux sources, nœuds, et sorties du réseau. L'effet des contraintes de débit (dues aux limitations dans le réseau) sur le *QCFD* a été formulé et analysé. On décrit le calcul de *QCFD* aux jonctions par l'addition des vecteurs d'apports. La méthode a été étendues numériquement aux mélanges non linéaires du fait de la liaison avec la salinité de l'eau. L'utilisation de cette méthode permet le calcul de *QCFD* aux nœuds intérieurs des réseaux, y compris les jonctions de dilution. L'effet de la topologie de réseau et du sens d'écoulement a été discuté. L'application et la démonstration suivront dans le prochain papier de cette série. Copyright © 2008 John Wiley & Sons, Ltd.

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INTRODUCTION

The rapid increase in the global population will require a similar increase in agricultural production of about 50% by the year 2025, most of which will be in developing countries. About two-thirds of the needed increase in food production in developing countries must come from existing crop land, most of which is irrigated land. The lack of water supplies for irrigation is among the bottlenecks in the desired expected increase in food production. Use of saline water for irrigation was therefore suggested as a new source of irrigation water (Rhoades, 1999). Efficient use of saline water for irrigation requires appropriate development in the water supply system to improve system design and operation, which will account for water quality aspects in addition to the classical hydraulic design. The concept of multiquality water supply systems was therefore introduced by Sinai *et al*. (1985, 1987), Shah and Sinai (1985, 1988), Shamir *et al*. (1991), Ostfeld and Shamir (1993), Cohen *et al*. (2000a, b, c, 2004a, b), Percia *et al*. (1997), and Ostfeld (2005).

Interest in multiquality water supply networks in recent years has led to the development of many models for their design and operation, e.g. Rossman and Boulos (1996), Rossman (2000), Clark *et al*. (1994), Pessen *et al*. (1986, 1989), Reike *et al*. (1987). Since the topology and most of the components and layout of a water supply system remain unchanged for many years, it is useful to decompose the computational process for simulation or design of multiquality irrigation water supply systems into two levels: (a) a layout level, and (b) a simulation/optimization operation level. In the layout level, the computations can be performed offline, i.e. not in real time, while in the simulation/optimization level, they are carried out online, or at least at frequent intervals to provide real-time estimation of the state and decision variables.

Unlike conventional hydraulic design of irrigation water supply systems, the design of multiquality systems requires an integrated approach which considers the hydraulics as well as water quality aspects of the system. Here the design methods suited for multiquality networks are suggested. In a follow-up paper (Sinai and Dalins, 2008), the effect of network layout and a design of a real case are demonstrated.

Several important relationships can be computed at the layout level for design purposes, including the influence of the network topology on input–output relations of flow and water quality parameters. This paper describes these relations between the state variables and the network topology by means of the feasibility domain (*FD*) approach; more specifically, the *Q–C* feasibility domain (*QCFD*) which is the domain of all feasible discharges and salinity concentrations as a measure of water quality in the network nodes.

The (*FD*) concept is not new, having been used to display the feasibility of supply and consumption combinations. Shamir *et al*. (1991), and to some extent Dalins (1986), used this idea to analyze the possibilities of supply in multiquality networks. Pessen *et al*. (1986, 1989) made use of similar ideas to analyze the attainable operating range of mixing junctions in irrigation and water supply systems. Water supply has two components: discharge (Q) and quality as determined by conservative constituents (ions) concentration (C). It has been found useful to analyze the supply by means of a Q–J diagram, where Q is water discharge rate and J is solute flow rate ($J = QC$). The multiquality flow phenomenon can be described by vector calculus, where the water discharge vector $\boldsymbol{Q}$ and the solute flow rate vector $\boldsymbol{J}$ are the state variables. The concentration, C, is obtained from the derivative$C = \mathrm{d}\boldsymbol{J}/\mathrm{d}\boldsymbol{Q}$. A position vector P in the Q–J diagram determines the state of water discharge–quality and is written (vectorally) by $\boldsymbol{P} = a\boldsymbol{1_Q} + b\boldsymbol{1_J}$, where $\boldsymbol{1_Q}$ and $\boldsymbol{1_J}$ are unit vectors along the Q and J axes, respectively, and a and b are the components of $\boldsymbol{P}$ in these directions. The *Q–C* feasibility domain and the vector calculus method of the above were found as a useful tool for design of multiquality irrigation water supply systems as is demonstrated below.

DESIGN OF MULTIQUALITY IRRIGATION WATER SUPPLY SYSTEMS

The design of multiquality irrigation water supply systems should consider water quantity, as well as water quality aspects. Crop consumptive demand for amount of irrigation water, water supply hardware and irrigation methods

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dictate the hydraulic design of irrigation systems. However, interrelations among irrigation water salinity, crop salinity tolerance level, leaching fraction (LF), leaching requirements (LR) and yield vs. salinity functions reveal a quite complicated relationship between irrigation hydraulic factors and salinity (Hoffman and Durnford, 1999; Letey, 1999; Rhoades, 1999). Cohen *et al*. (2000a, 2004a, b) considered the loss of agricultural yield in irrigated fields, due to irrigation with saline water. They used the Maas and Hoffman (1977) model for yield vs. salinity function and demonstrated how an optimal policy of long-term operation of a multiquality irrigation water system can reduce the overall cost of operation by selecting optimal consumption values of irrigation water salinity in individual fields.

A sensitivity analysis (Cohen *et al*., 2004b) revealed the relative importance of irrigation water salinity. They showed in a case study of a real regional water supply system in an agricultural zone in Israel that the relative value of yield loss due to the salinity component in the overall operation cost function of the system was the highest component. It can be concluded from these previous works that widening the *QCFD* by increasing the salinity range of available irrigation water in every field enables optimal design of crop types, leaching fraction and irrigation practice to minimize yield loss due to water salinity. In general, as the *QCFD* becomes wider, the flexibility in meeting variable crop requirements for irrigation water amount and quality, increase also; hence, the importance of design which considers the *QCFD*s of the individual agricultural consumers.

Design of multiquality irrigation water systems should therefore consider the *QCFD* of the sources and the agricultural consumers to maximize the benefit from meeting optimal crop demand for irrigation water quality, taking into account different costs for water at the sources level which obviously depend on water quality.

Cohen *et al*. (2000a, 2004a) developed a method to extend water quality issues and to consider multiple ions and also quality factors as sodium absorption ratio (SAR), which are composed of functional relations of ion concentration and other water quality factors. Use of their methods enables us to widen the range of water quality factors considered in the *QC* design of multiquality irrigation water supply systems.

DESIGN STEPS

The analysis, so far, demonstrates the importance of water quality at the sources level, network layout and control devices in computation of the *QCFD* at the agricultural consumer outlets. However, since the major process which changes water quality inside the network is dilution, it requires proper hydraulic and water quality control. Sinai *et al*. (1985, 1987), Shah and Sinai (1985, 1988), Pessen *et al*. (1986, 1989), Percia *et al*. (1997), Rossman (2000), Cohen *et al*. (2000c), and Ostfeld (2005) developed models and methods for simulation, automatic control and optimal operation of multiquality networks. Based on the cumulative knowledge gained during two decades of studying multiquality networks, the following design steps are suggested:

(a) Planning the network layout to meet agricultural demand for water quality and quantity of the individual fields.
(b) *Q–C* design of layout and hydraulic control devices according to the *QCFD* method.
(c) Hydraulic design of the network's control devices, pipe diameters valves, pumps, etc.

The present paper focuses on the *Q–C* design (step b) of multiquality irrigation water supply systems. In a follow-up paper Sinai and Dalins (2008) present detailed design of a real case.

SOURCE–CONSUMER APPROACH

Part of the initial analysis and design of a multiquality irrigation water supply system can be carried out using what may be termed the *source–consumer approach*. Only the sources and consumers are considered in the water system, neglecting, at this stage, constraints imposed by the network facilities. The supply problem is first analyzed as an assignment problem.

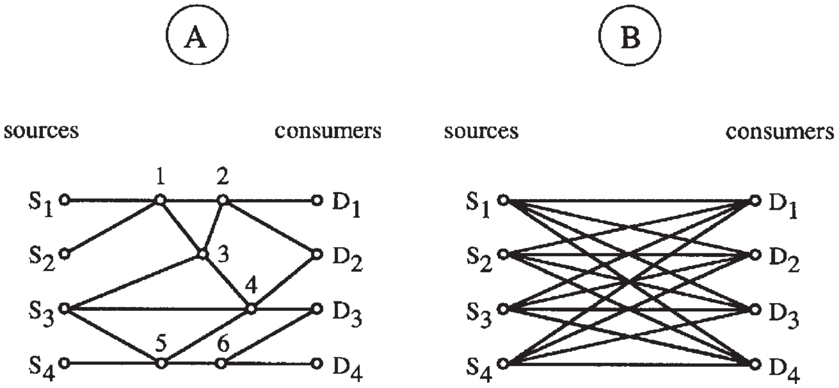

Figure 1. Use of bipartite graph method to transform a real network to a sources–consumers network: (A) real network; (B) sources–consumers representation

The real network (Figure 1A) is transformed into a complete bipartite graph (CBG) of the source and consumer nodes where every source is connected to all the consumers (Figure 1B). In the real network, at least one flow path exists connecting each source to all the consumers, so the CBG shown in Figure 1B is equivalent to the real network in Figure 1A as far as connectivity is concerned. Note that more than one path is possible between a source and a consumer in the real network, for example the paths (S_1,1,2,D_2), (S_1,1,3,4,D_2) and (S_1,1,3,2,D_2) are all possible connections between source S_1 and consumer D_2 (Figure 1A). This connection is shown in the CBG (Figure 1B) as a single line connecting source S_1 and consumer D_2. The supply problem in this approach is a classical assignment problem, whose solution can provide useful information, for example how much water at what quality can be supplied from each source with given quantity constraints at the sources. Maximum flow constraints can also be imposed on each link between the sources and the consumers. As these constraints are tightened and become closer to the real capacities of network links, the supply problem changes from an assignment to a network problem. Useful analysis can be carried out with this simple source–consumer form of the CBG, as described in the following section.

ANALYSIS OF CONSUMERS' DEMANDS USING THE FEASIBILITY DOMAIN CONCEPT

One of the most important questions in the design of irrigation water supply systems is the feasibility of supply. In other words, can the demands of the agricultural consumers (irrigated field) be met by the supply capability at the sources? In a multiquality irrigation water supply system, this question incorporates the issue of water quality. A prescribed volume of water is to be supplied at a given flow rate, pressure head and within specified water quality limits. This problem becomes a solute transport problem with three major variables: *Q* – water flow rate, *H* – head, and *C* – concentration of conservative water quality parameter (see Cohen *et al.*, 2000a, or Sinai *et al.*, 1985 for a more detailed discussion). The general *QCH* solute transport problem can be decomposed into two almost independent problems: (a) water flow (*Q*) and water quality parameters in solute concentration (*C*) are the parameters of the *QC* problem, and (b) water flow (*Q*) and water head (*H*) are the parameters of the *QH* problem. In previous papers, Sinai *et al.* (1985) and Cohen *et al.* (2000a) referred to these problems as the chemical (*QC*) and the hydraulic (*QH*) problems. Simplified models were developed (Cohen *et al.*, 2000a, 2004a, b)for optimal water supply in multiquality networks using *QC* problems with general hydraulic constraints to keep the solutions within hydraulically feasible bounds. The feasibility of supply from the sources to meet consumer demand can, therefore, be checked for these types of models. It is useful to perform these checks on a *Q–J* diagram.

Analysis of the supply capability of sources

Single source. Consider a single source as shown in Figure 2. The supply capability of the source can be depicted on a *Q–J* diagram (following Dalins, 1986). Six cases are shown in Figure 2:

(A) Constant source water discharge (flow) rate (Q), and water quality concentration, (C). There is one feasible point in the *Q–J* plane, and the slope of the vector point is the quality concentration, C, since $J = CQ$ and$C = \mathrm{d}J/\mathrm{d}Q$.

(B) Constant source discharge (Q) and variable concentration in the range $\Delta C = C_{\max} - C_{\min}$. The feasible region lies on a vertical line at Q, between the two slopes C_{min} and $C_{\max}$.

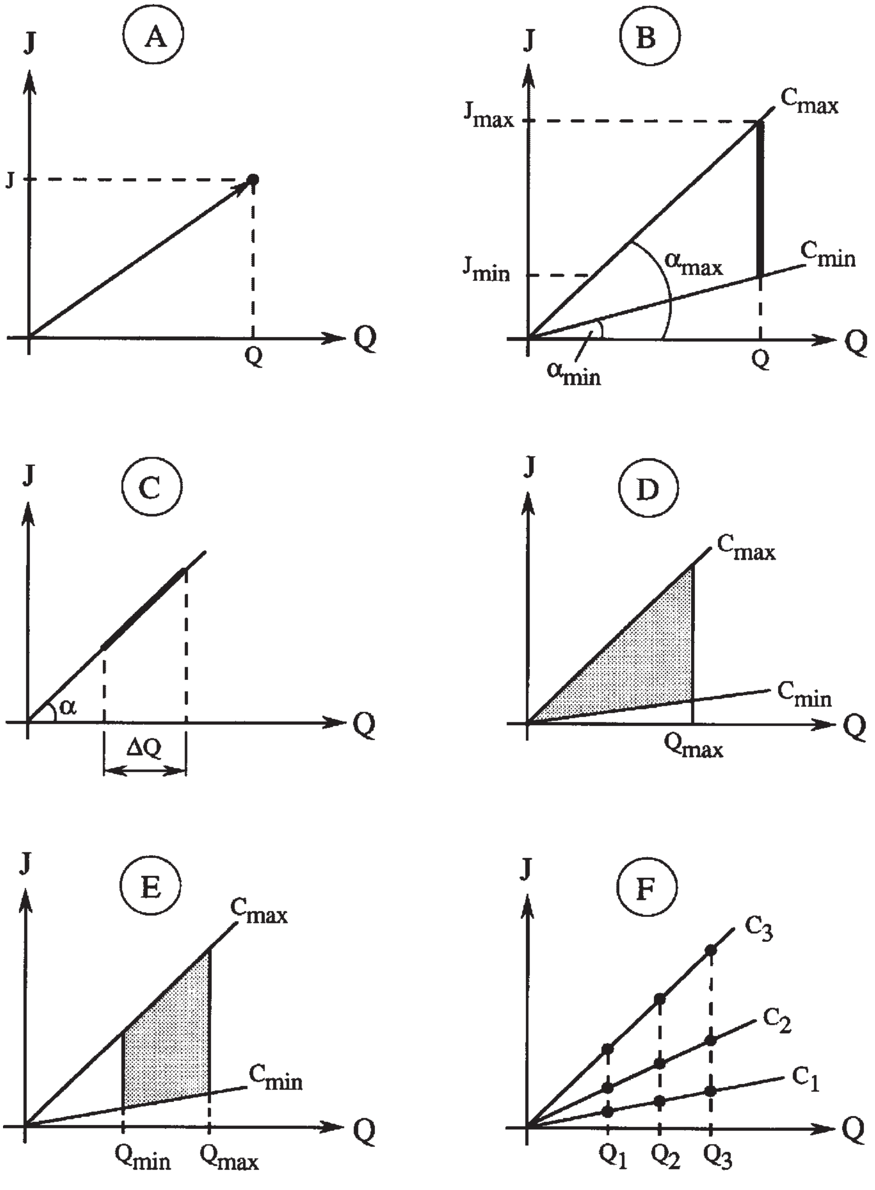

Figure 2. Graphical representation of some supply *QCFD*s: (A) constant discharge and water quality; (B) constant discharge and variable quality in the range ΔC; (C) variable discharge in the range ΔQ and constant quality; (D) variable discharge in the range $0 < Q < Q_{\max}$ and variable quality ΔC; (E) variable discharge in the range $Q_{\min} < Q < Q_{\max}$ and variable quality ΔC; (F) discrete values only

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(C) Constant concentration, and variable discharge in the range $\Delta Q = Q_{\max} - Q_{\min}$. The feasible region lies on the C sloped line, in the range $Q_{\max}$–$Q_{\min}$.

(D) Discharge and concentration are variable in the ranges $0 < Q < Q_{\max}$ and $C_{\min} < C < C_{\max}$. The feasible region is the shaded area between the two slopes C_{min} and $C_{\max}$

(E) As for case (D), except that the discharge range is limited to $Q_{\min} < Q < Q_{\max}$

(F) Only discrete values are possible: $Q = Q_1$, Q_2, Q_3 and $C = C_1$, C_2, C_3.The feasible region consists of nine discrete points.

Two sources, linear mixing. A system with two or more sources with different water qualities introduces the issue of network dilution. Waters of different qualities are mixed within the network, resulting in the supply of intermediate qualities at the demand nodes. This is demonstrated by a case of two sources and two consumers with different concentrations of the same quality parameter (Figure 3).

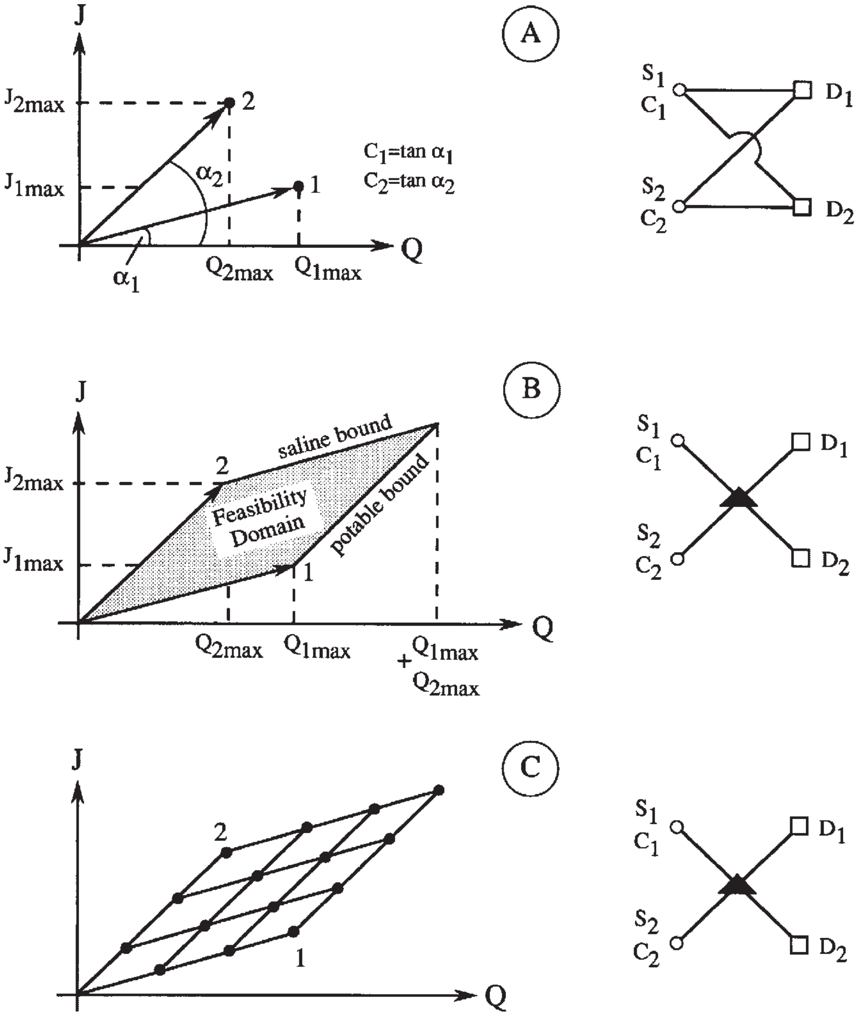

Figure 3. Feasibility domains of two consumers with supply from two sources of different fixed qualities: (A) feasibility domains of the two consumers without dilution at the network; (B) feasibility domain of the two consumers where dilution in the network is possible and the supply discharge can be varied continuously; (C) feasibility domain of the two consumers with dilution at the network and the supply discharges are variable in given jumps

Case A is a simple system of two sources, S_1 and S_2, with concentrations C_1 and C_2, respectively, as shown in Figure 3A (right). There are two consumers, without dilution. The feasible supply domain is shown on the *Q–J* diagram as two vector points, **1** and **2** (Figure 3A, left). The horizontal components of these vectors are $Q_{1\max}$ and $Q_{2max.}$ The tangent of the angles α_1 and α_2 represents the source concentration where $C_1 = \tan\alpha_1$ and $C_2 = \tan\alpha_2$.

In case B, shown in Figure 3B (right), dilution can take place. The discharge range of source S_1 is $0 < Q < Q_{1\max}$ and that of S_2 is $0 < Q < Q_{2\max}$. The *QCFD* of supply is the shaded parallelogram area defined by the vector addition of vector **1** with vector **2**. Based on the commutative law for addition of vectors (**1 + 2 = 2 + 1**), the vector addition **1 + 2** (increasing order of concentration) is the lower boundary of the *QCFD* (potable bound) in Figure 3B (left), and the vector addition **2 + 1** (decreasing order of concentration) is the upper boundary (saline bound) in Figure 3B. Every point inside this domain can be obtained by a vector addition of two sub-vectors $m\boldsymbol{i} + n\boldsymbol{j}$, where m and n are scalars and $\boldsymbol{i}$ and $\boldsymbol{j}$ are unit vectors in the direction of vectors **1** and **2**, respectively (note: $0 < ||m\boldsymbol{i}|| < ||\mathbf{1}||$ and $0 < ||n\boldsymbol{j}|| < ||\mathbf{2}||$). Each point in this *QCFD* represents a supply case, given by the position vector of the point, whose component with respect to *Q* is the water discharge and whose derivative is the concentration,$C = \mathrm{d}J/\mathrm{d}Q$. Case B (Figure 3B) demonstrates that dilution enlarges the *QCFD* of supply.

The third case (Figure 3C) is more limited. Network dilution is possible but the discharge can only take place on discrete (rather than continuous) values. The *QCFD* of this case is defined by vector addition of the position vectors representing the discrete supply values. Only four discrete discharge values are possible in every source, therefore the feasible domain consists of 16 discrete points rather than a continuous domain as in case B.

Analysis of three or more sources is difficult to show graphically on a *Q–J* diagram. However, the method is similar to that of two sources.

Computing QCFD for variable discharge and concentration, nonlinear mixing

The most general case is where both *Q* and *C* of the inlet pipes to a dilution junction are not constant. The method of vectoral addition described above was not useful so a numerical method was suggested here as an alternative.

The QCFD numerical algorithm.

Step 1: set to $Q_1^* = Q_{\min}$, $\mathrm{J_i}* = J^*_{\min}$.

Step 2: Increase Q_i^* by $Q_{i+1}^* = Q_i^* + \Delta Q$; $\Delta Q = \underset{(n\ \text{integer})}{(Q_{\max} - Q_{\min})}/n$.

Step 3: Compute the saline bound from $J_i^{*s} = \max\{J_i^{*1} \ldots J_i^{*n}\}$ for all the inlets 1 . . . . *n* whereJ_i^{*s} is the *J* value of the saline bound $(J_i^* = Q_i^*\ C_i^*)$.

Step 4: Compute the potable bound from $J_i^{*p} = \min\{J_i^{*1} \ldots J_i^{*n}\}$ for all the inlets 1 . . . . n whereJ_i^{*p} is the *J* value of the potable bound $(J_i^* = Q_i^*\ C_i^*)$.

Step 5: If $Q_i^* = Q_{\max} - \ldots$ END. else – return to Step 2.

where $Q_i^{*1\ldots n}$, $C_i^{*1\ldots n}$ are the discharge and concentration values at the inlets 1. . . *n*, which can be changed with *Q*.

The network model presented below used this numerical method to compute *QCFD* in all the nodes of unfixed *Q* or *C* values.

Meeting consumer demands by the supply feasibility of the sources

An agricultural consumer is determined here as a field of the same crop of the same water quality (e.g. salinity) requirements. This field therefore demands: (i) a fixed water discharge which can be obtained from the irrigation rate multiplied by the irrigated area; and (ii) a fixed water quality (e.g. salinity). The demand of an agricultural consumer is therefore given by water discharge and water quality.

Agricultural consumer demands must be *within* the supply *QCFD* for the demand to be met. This condition can be tested in the *Q–J* diagram. Four types of agricultural consumers are demonstrated in Figure 4: (1) fixed demand (discharge and concentration); (2) fixed discharge demand and variable concentration; (3) fixed concentration and variable discharge demand; and (4) variable discharge demand and concentration.

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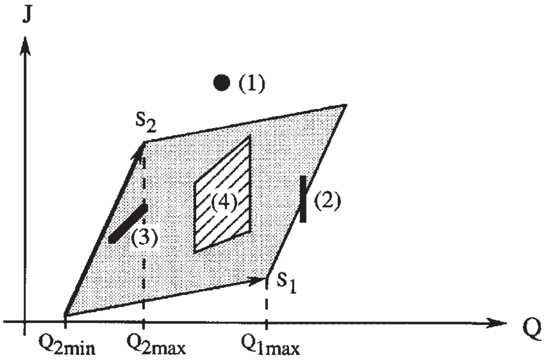

Figure 4. Demonstration of a check for feasibility of supply of a two-source and four-consumer water system

The simplest case is to draw, on the same *Q–J* diagram, the source supply domains and the consumer demand domains, in order to check if the demand domains are contained within the supply domains. The case of a system with two sources, dilution in the network, and the four consumers is also shown in Figure 4. The discharge at the sources can change continuously in the ranges $Q_{2\min} < Q_1 < Q_{1\max}$ and $Q_{2\min} < Q_2 < Q_{2\max}$. The shaded parallelogram which is formed by vector addition of source 1 and 2 is the supply *QCFD* of the two sources.

This case reveals that the demands of agricultural consumers 3 and 4 are completely within the supply *QCFD* of the two sources. This means that the entire demand of consumers 3 and 4 can be met; however, whether both can be supplied simultaneously cannot be determined directly, since this depends on the mode of operation and on the network carrying capacity. This case also shows that the demand of consumer 2 can only be partially met, since the concentration must be inside the range determined by the *QCFD*. The demand of consumer 1 cannot be met at all by this system.

EFFECT OF NETWORK TOPOLOGY AND FLOW CONSTRAINTS ON FEASIBILITY DOMAINS

The structure of a network affects water quality in a number of ways:

(i) The topological structure of the network layout determines the connectivity of the consumers to the sources and therefore determines what quality of water each consumer can receive.
(ii) Constraints on discharges in the pipes of the network affect dilution ratios indirectly and consequently water quality.
(iii) Dilution can take place in the network of two or more water flows with different qualities.

Network topology

We demonstrate the importance of network topology by analyzing two types of networks: source–consumer networks and dilution networks. The dilution network was analyzed in the follow-up paper by Sinai and Dalins (2008).

Source–consumer network. The sources are connected to the consumers directly with no dilution in the network, and thus water quality does not change within the network. A simple source–consumer network with three sources and three consumers is presented in Figure 5.

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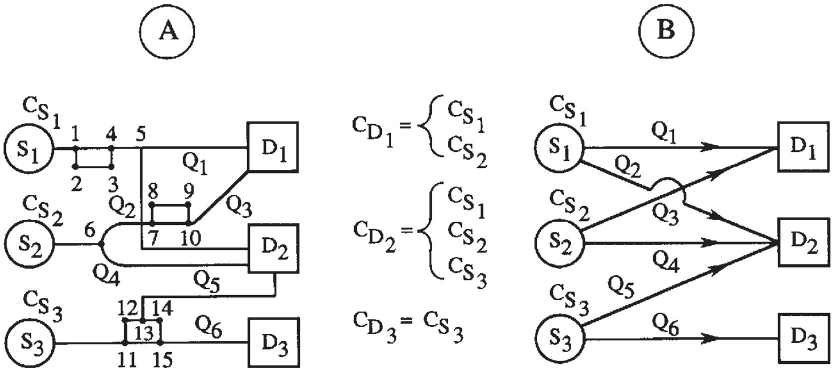

Figure 5. Demonstration of a sources–consumers network: (A) the real network; (B) the graph of that real network

The real network (Figure 5A) includes loops on the lines from the sources. Consumer D_1 receives water from sources S_1 and S_2, consumer D_2 from S_1, S_2 and S_3, and consumer D_3 from S_3 only. The real network is simplified by drawing the network graph (Figure 5B) of the link connections from source to consumers. Let $Q_1 ... Q_6$ be the maximum possible discharge through the connecting network sections, and Q_{S1}, Q_{S2}, Q_{S3} the maximum source flows. Conservation of water yields:

$$Q_1 + Q_2 \le Q_{S_1}, \quad Q_3 + Q_4 \le Q_{S_2}, \quad Q_5 + Q_6 \le Q_{S_3}$$

The supply domains of the sources and the *QCFDs* of the three consumers are shown in Figure 6.

The supply domain of the three sources is bounded by vectors S_1, S_2, and S_3 in Figure 6A. Consumer D_1 can receive two water qualities, denoted by C_{S1} and C_{S2}:– the original concentrations of sources S_1 and S_2 (Figure 6B). Consumer D_2 can receive all three qualities, C_{S1}, C_{S2} and C_{S3} (Figure 6C). Consumer D_3 is linked to source 3 only and, therefore, can only receive water with quality C_{S3} (Figure 6D).

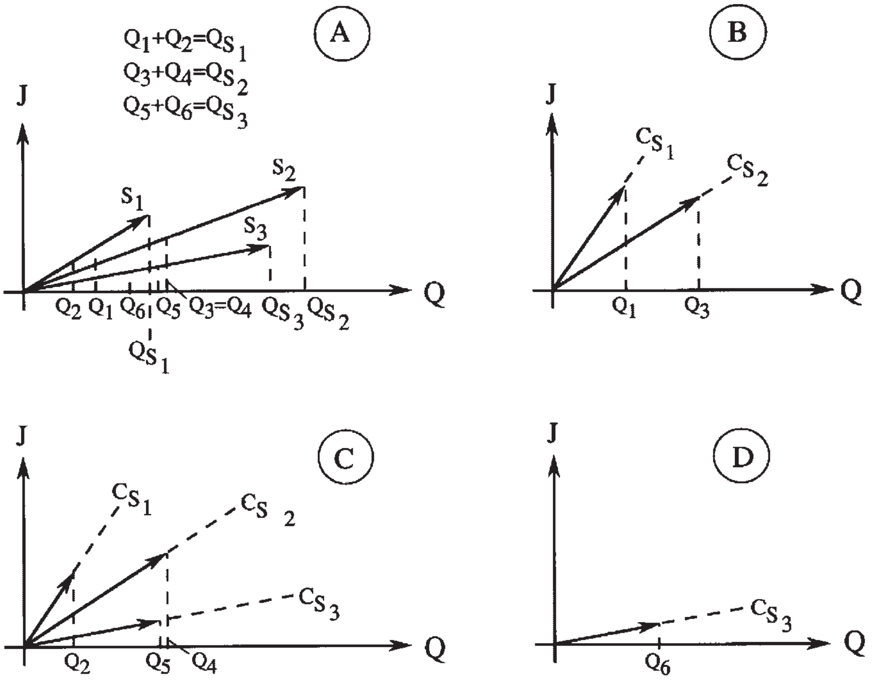

Figure 6. The supply *QCFD* of sources S_1, S_2 and S_3 in Figure 5, bounded by maximum discharges through the connecting network: (A) and the *QCFD*s of the consumers: of D_1 in Figure 6B; of D_2 in Figure 6C; and of D_3 in Figure 6D

Effect of water discharge constraints on the feasibility domain

The *QCFD* at the outlets also depends on maximum discharge constraints in the links. The design model therefore computed a truncated *QCFD* for every pipe/link which was the unbounded *QCFD*, minus the domain of $Q > Q_{\max}$ of the inlet and outlet pipes of the junction considered. The $Q_{\max}$ bounded *QCFD*s are demonstrated in the example in the next paper of this series (Sinai and Dalins, 2008).

CONCLUSIONS

The design of irrigation–drinking water supply systems presents serious difficulties because of the interrelations between water quantity and quality aspects. The design of conventional uniform water quality supply systems was traditionally a hydraulic design, i.e. irrigation rates, scheduling, pressure and discharge distribution in the network links and nodes. Recently, however, the issue of water quality, both for irrigation of various crops and for drinking, has emerged.

The present paper addresses a new design concept for such problems. A new design tool was suggested – the *Q–J* diagram, where water discharge (Q) and solute discharge $J = QC$ ($C =$ solute concentration) were the horizontal and vertical axes, respectively. The combined state variable-flow in the network links was determined by a point in the *Q–J* diagram. The components of the position vector $\boldsymbol{P}$ of that point are the water discharge $\mathbf{Q} = Q\ \mathbf{1}_{\boldsymbol{Q}}$ and the solute discharge $J = J\ \mathbf{1}_{\boldsymbol{J}}$. Feasibility of supply was therefore defined by a feasible domain bounded by $Q_{\min},\quad Q_{\max}$ and $J^{\min}_{(Q_{\min})},\ J^{\max}_{(Q_{\max})}$. Every position vector of any point inside this feasible domain was represented as a feasible *Q–C* supply (Q denoted water discharge and C denoted solute concentration). This paper assumes conservative substances only. Application of this so-called *QC* feasibility domain (*QCFD*) enabled rigorous analysis of the combined aspects of water quantities ($\boldsymbol{Q}$) and qualities ($\boldsymbol{C}$). *QCFD* of a single source and of multiple sources of various water qualities with and without mixing dilution inside the network junctions were successfully drawn and analyzed using the *Q–J* diagram. The cumulative combined *QCFD* of all the sources was computed. Several types of demands of irrigation and drinking water consumers were also plotted on the same *Q–J* diagram and feasibility of supply was evaluated.

The demands of these consumers were met if the demand *QCFD*s were found inside the supply *QCFD* of the sources. This test was conducted first on the sources–consumers level and followed by a complete network evaluation. *QCFDs* of every node inside the supply network were computed, so feasibility of supply was tested for every individual consumer outlet. This test also indicated possibilities of simultaneous supply of water to various combinations of aggregated consumers. A model (*QCFD*) was developed, which computed all the supply *QCFD* of the networks nodes for a given flow pattern (*FP*). This *QCFD* model is presented in the follow-up paper (Sinai and Dalins, 2008). Evaluation of all the *QCFDs* for every feasible *FP* (*FFP*) enabled a complete analysis of all feasible water discharges and solute concentrations of the examined supply systems. Pipe diameters and discharge distribution of a network, with diverse water quality sources and irrigation of different salinity tolerance levels and of drinking water consumers, were determined using the proposed *QCFD* concept. However, further research is needed for examination of the effect of flow direction changes in the supply networks on the *QCFDs* of individual nodes.

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