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September 13, 1999

Mr Brett Tucker
Program Coordinator
National Program for Irrigation Research and Development
Land & Water Resources R&D Corporation
PO Box 1257 Griffith NSW 2680

Dear Brett,

The enclosed document **An Evaluation of the Applicability of Genetic Algorithm Technology to Flow Management of Open-Channel Gravity Systems: Final Report for LWRRDC Project UAD14** is the Final Report regarding the Land and Water Resources Research and Development Corporation funded project.

I apologise for the lateness of this document, and thank you for your involvement in this project.

Sincerely,

Dr J.B. Nixon

PS. In the report itself, mention is made of an attachment consisting of a complete set of all documents associated with this project. This is also enclosed.

encl: An Evaluation of the Applicability of Genetic Algorithm Technology to Flow Management of Open-Channel Gravity Systems: Final Report for LWRRDC Project UAD14

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Project Title

An Evaluation of the Applicability of Genetic Algorithm Technology to Flow Management of Open-Channel Gravity Systems

LWRRDC Project Reference Number

UAD14

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Abstract

Development of efficient scheduling systems for water delivery via open-channel irrigation networks is important to irrigation authorities and individual irrigators. There are increasing demands on irrigation authorities to be efficient in their operations by making the best use of existing infrastructure, providing a high level of service to their customers, and minimising water losses.

Water ordering for open-channel delivery networks commonly uses an "advance order" system. Many irrigation authorities using this system record orders and schedule deliveries with computerised assistance. Irrigation order schedules must be devised by water planners to meet the orders, taking into account water availability, network capacity constraints, operating efficiency, and customer satisfaction. Little direct assistance, however, is available to water planners while they balance these and many other requirements in trying to identify optimal schedules for irrigation water deliveries. Thus, there is considerable scope for the development of decision support tools to aid planners in this complex scheduling activity.

The research carried out in Project UAD14 examined the use of genetic algorithm (GA) optimisation to identify water delivery schedules that achieve the best possible outcomes for a set of objectives, while satisfying a set of constraints. The identification of a set of significant objectives and important constraints was one major outcome of the study. The development of suitable representations of these factors for incorporation within the GA framework was another. Results were obtained initially for an idealised system of five irrigators on a channel spur, in which the GA technique efficiently identified the known optimal schedule for the simple irrigation order optimisation problem.

Actual ordering regimes corresponding to irrigation season periods operated in the past by an actual water authority were then used to generate results of more general interest. These real-world trials were carried out in the Department of Civil and Environmental Engineering at The University of Adelaide (the University) in conjunction with Goulburn–Murray Water (G–MW) and Rubicon Systems Australia Pty Ltd (Rubicon). They used G–MW's Tatura, Victoria, area historical field data and Rubicon's Irrigation Planning Module (IPM) ordering and management software. The University's GA software was integrated with Rubicon's IPM software by the two groups co-developing an appropriate application programming interface (API) between the two otherwise independently developed software layers.

Results have shown great promise in the ability of GA techniques to determine irrigation order schedules that provide good first approximations suitable for investigation. The intention is that these schedules will be reviewed and finalised by G–MW irrigation planners, and then implemented by Tatura network field operators.

A proposed new research project (Simpson et al., 1999a) aims to substantiate this promise, and quantify the benefits and costs associated with implementation of GA optimisation to irrigation scheduling in the day-to-day running of an open-channel network (in the Tatura area) by an Australian water authority (G–MW).

Acknowledgements

The research team gratefully acknowledges the funding and/or in-kind support received from the following corporations.

- Land and Water Resources Research and Development Corporation/
  National Program for Irrigation Research and Development
- Goulburn–Murray Water
- Rubicon Systems Australia Pty Ltd
- The University of Adelaide

Note

A three-fold A4 colour pamphlet describing this research for non-technical audiences is available on request.

1 Summary of Methods and Modifications

The genetic algorithm (GA) optimisation technique has been used to develop a computer model to assist in determining optimal irrigation water delivery schedules.

The basics of the GA method were outlined at the inaugural Steering Committee meeting (Simpson, 1997). An outline of the application of the GA technique to irrigation order scheduling was presented at two Australian National Committee on Irrigation and Drainage (ANCID) conferences (Dandy et al., 1997; Nixon et al., 1998c). The proposed methods were discussed in the funding application for this project (Dandy and Simpson, 1996a).

In the following, pertinent aspects of these methods as proposed are summarised, and modifications in their implementation (with reasons) are stated.

1.1 Genetic Algorithms

A GA is a search algorithm, based on natural selection and the mechanisms of population genetics (see Goldberg, 1989; Holland, 1992; Michalewicz, 1996, for example). The GA technique has its roots in the biological processes of "survival of the fittest" and adaptation. This project involved the application of these ideas, and the experience in this field of the researchers involved, to the problem of optimising the delivery of irrigation orders via open-channel irrigation systems.

1.1.1 String Representation

Each irrigator places an order for a requested starting time, of a desired duration (in hours), with a specified flow rate in megalitres per day (ML/day). Each order to be scheduled for a *plan day* is encoded in the GA as a string of numbers, with each position in this string representing the integer number of hours the requested order is scheduled to be shifted. A negative shift corresponds to "bringing forward" an order, while a positive shift corresponds to "holding off" an order.

In the funding proposal it was stated that the form of encoding was to be that of a binary-bit string. The integer form was actually implemented, and proved to be a more natural representation.

1.2 Scheduling Constraints

A count of the number of orders for which the start times were requested within a *planning period* relative to the plan day determines the number of orders to be scheduled, and hence the length of the strings. The orders are allowed to be shifted by the GA process, as described in Section 1.1.1, such that the scheduled start times always remain within the planning period.

1.3 Genetic Algorithm Operators

The GA operates on a "population" of alternative schedules for irrigation water delivery. Initially, the population of solutions (with, for example, a population size of 150 strings) is randomly generated. An improved population is then produced in the next "generation" by using three GA operators of selection, crossover, and mutation. Selection is a "survival of the fittest" process, and involves the choice of which "parent" strings, of "high" fitness, will form a "mating pool" used to provide the characteristics of subsequent "child" strings. Crossover is a partial exchange of order shift values between parent strings, that "breeds" child strings that are guaranteed to satisfy the imposed constraints discussed in Section 1.2. Mutation occasionally alters the order shift value at a randomly selected string position to a different, but allowable, value. The termination of the reproduction process may be governed either by a maximum number of "generations" predetermined by the user, or a variable number determined during the "evolution" process by the algorithm itself, as it "converges" to a final population.

1.4 Flow Rate Time-Series

Flow rate time-series are calculated to determine the flow regime corresponding to an irrigation order schedule. Each time-series represents the flow past a specified control structure as a series of values for flow rate (in ML/day) versus time (in hours). At many of these control structures, a channel capacity (in ML/day) specifies a maximum flow rate that, ideally, should not be exceeded.

Each flow rate time-series takes into account the requested order times and the scheduled order-shifts. Conceptually, at the end of an order at a "finishing" offtake point, water is made available for the beginning of a "following" order at a "starting" offtake point. These lags for water in the system, known as "travel times", are taken into account.

1.5 The Research Approach

An incremental approach was used in the development and refinement of the GA technique, as applied to optimising irrigation water schedules. In the first instance only a few objectives were used to determine the "fitness" of schedules. Once these were fully implemented, other objectives were then included in the formulation.

Results were obtained initially for an idealised system of five irrigators on a channel spur, in which the GA technique efficiently identified the known optimal schedule for the simple irrigation order optimisation problem.

Actual ordering regimes corresponding to irrigation season periods operated in the past by an actual water authority were then used to generate results of more general interest. These real-world trials were carried out in the Department of Civil and Environmental Engineering at The University of Adelaide (the University) in conjunction with Goulburn–Murray Water (G–MW) and Rubicon Systems Australia Pty Ltd (Rubicon). They used G–MW's Tatura, Victoria, area historical field data and Rubicon's Irrigation Planning Module (IPM) ordering and management software. The University's GA software was integrated with Rubicon's IPM software by the two groups co-developing an appropriate application programming interface (API) between the two otherwise independently developed software layers. This proved to be a suitable approach, obviating the further development by the University of an ordering simulation program with extensive user interfaces, by utilising the sophistication of Rubicon's existing IPM software, and minimising the effort involved in developing computer code to access G–MW's Tatura data.

1.6 Scheduling Objectives

Irrigation authority personnel at G–MW were interviewed to determine the objectives that they use and consider to be important in delivering irrigation water to irrigators in an appropriate manner. Those objectives chosen to be implemented in the GA software were then subject to a process of review and refinement over the period of the project.

1.6.1 Determining Scheduling Objectives

The following *optimisation objectives* were determined to apply to a "good" schedule, and were found to be most readily implemented within the GA framework.

A. Encourage certain request variations and discourage others.

B. Discourage late notice orders.

C. Avoid channel capacity exceedance.

D. Minimise channel flow rate variations.

E. Minimise control structure regulations.

F. Satisfy customer service agreements.

It was stated in the funding application that, in the GA optimisation, consideration would be given to objectives including the proposed *example objectives* to:

(i). match as closely as possible the total inflow to the channel system with the total demand, taking best advantage of the hydraulic capacity of the system as irrigators come on and off;

(ii). minimise spillage by producing constant flow in the channels where possible:

(iii). maximise the number of irrigators who receive their water at the designated time;

(iv). ensure the "discomfort of being moved is socialised across all irrigators", i.e. that the same irrigator or group of irrigators is not moved from their desired ordering time(s) every time they place an order; and

(v). either:

   (a) minimise the travel time of the operator who has to set the regulating structures and in some cases the Dethridge wheels to bring on or turn off the supply to irrigators (e.g. it is undesirable to travel back and forth to the opposite extremities of the irrigation district); or

(b) optimise the remote monitoring and control which may be implemented throughout the network.

Example objective (i) was proposed to be implemented by minimising the sum of squares differences between system inflow and outflow for each hour. Optimisation objective C was implemented instead, to account for channel capacity at individual reaches rather than network capacity overall (see fitness measure 2(a) of Section 1.6.2).

Example objective (ii) proposed was implemented by optimisation objective D, in the manner described by fitness measure 2(b)i of Section 1.6.2.

Example objective (iii) proposed was implemented by optimisation objective A in the manner described by fitness measure 1(a) of Section 1.6.2. The objective implemented is somewhat more ambitious than the objective proposed, in that the aim is to both maximise (quantitatively) the number of requests which *are* met *and* to optimise (qualitatively) the manner in which requests are *not* met.

Example objective (iv) was not implemented, as proposed. The appropriate information defining the "many to many" relationship between orders and irrigators as well as the statistical history of irrigators' orders as-requested compared to as-delivered was not available to the GA module through the API layer from the IPM software. Optimisation objective F does, however, account for certain other aspects of customer service (see fitness measures 3(a)–(b) in Section 1.6.2).

Neither of the alternatives proposed in example objective (v) were implemented because the appropriate information with respect to, respectively, the topology of the network and the identification of supervisory control and data aquisition (SCADA) equipped control structures was not available to the GA via the API from IPM. The somewhat analogous optimisation objective E—of minimising the number of regulations required at control structures (either manually by irrigation operators, or automatically by remote control)—was, however, implemented (see fitness measure 2(b)ii of Section 1.6.2).

None of the example objectives proposed encapsulated the optimisation objective B. The implementation of this objective, in the manner described by fitness measure 1(b) of Section 1.6.2, thus constitutes a further advance in objective implementation with respect to that which was proposed.

1.6.2 Defining Objective Fitnesses

For each of the optimisation objectives A–F listed in Section 1.6.1, a corresponding *fitness measure* was developed. These fitness measures are enumerated below, and the corresponding optimisation objectives listed (in brackets). A brief explanation of how each measure is calculated so as to "reward" or "penalise" schedules in relation to its objective is also itemised.

1. Order Fitness Constituent (A)

   - Given by the multiplication of the following two fitness measure factors, as calculated for each order.
   - The multiplication is computed for each order and then averaged over the total number of orders.

   (a) Order-Shift Fitness Constituent Factor

   - Determined by two functions defining fitness values related to the shift applied to an order as requested to give the order as scheduled. These functions, overall, reward schedules which shift the fewest orders and, otherwise, reward and/or penalise those which shift orders in a manner determined by G-MW personnel to be beneficial to both irrigators and water authorities.
   - One function applies to orders of low duration, while another applies to orders of high duration, where the cut-off between "low" and "high" is user-specified.

   (b) Order-Notice Fitness Constituent Factor

   - Determined by a function defining a fitness value related to the ratio of the order notice given by the irrigator to that user-specified to be the minimum desired. This function penalises schedules with orders giving less than the desired notice, but does not reward those with orders giving more notice.

2. Flow Rate Time-Series Fitness Constituents

   - The following fitness constituents are calculated for each of a number of specified control structures and then averaged over that number of control structures.

(a) Time-Series Flow Rate Maximum Fitness Constituent (C)

- The number of control structures at which this is computed is equal to the count of those for which a capacity is defined in the IPM database.
- Determined by a function defining a fitness value related to the ratio of the maximum value of the flow rate time-series to the flow rate capacity of the associated control structure. This function penalises schedules with control structures which are over capacity, but does not reward those with control structures which are under capacity.

(b) Time-Series Flow Rate Variations Fitness Constituents

- The number of control structures at which these are computed is equal to the count of those for which a "linking authority" is set in the IPM database.
- The ratio of a measure of the flow rate variations required by the schedule as proposed by the GA to that of the schedule as requested by the irrigators is computed.
- The exact form of the function defining a fitness value related to this ratio is user-specified. The general functional form penalises GA-proposed schedules with control structure flow rate time-series variation greater than irrigator-requested schedules and visa versa.
- The same function is used for the following two fitness constituents.
- The two associated flow rate variations measures are also described below.

i. Scheduled Deviations Fitness Constituent (D)

- The time-series is that determined by an algorithm in the IPM software system (using water mass balance and network hydrodynamics) to represent the flow rate variations required, at each control structure, to *define* the proposed schedule.
- The measure of scheduled flow rate variations, from which the corresponding fitness is calculated using the function discussed above, is given by the standard deviation of this scheduled variations time-series.

ii. Planned Regulations Fitness Constituent (E)

- The time-series is that determined by an algorithm in the GA software module (from the IPM scheduled variations time-series) to represent the flow rate regulations required, at each control structure, to *operate* the proposed schedule.
- The measure of planned flow rate regulations, from which the corresponding fitness is calculated using the function discussed above, is given by the count of flow rate variations in this planned regulations time-series.

3. Customer Service Fitness Constituent (F)

- Only those customers which give at least a (user-specified) minimum amount of order notice are considered in the determination of this fitness constituent.
- Defined so as to enforce certain aspects of the customer service agreement between the water authority and the irrigators.
- Given by the average of the two fitness functions described in the following.
- The two fitness functions do not reward schedules with order percentages which exceed a user-specified value, but penalise those with orders which do not.

(a) Agreed-to "Same Date" Service

- Determined by a function defining a fitness value related to the percentage of orders which are scheduled to be delivered on the same date that they were requested.

(b) Agreed-to "Nearest Dates" Service

- Determined by a function defining a fitness value related to the percentage of orders which are scheduled to be delivered on the same date as, or within one day of, the date they were requested.

1.6.3 Combining Scheduling Objectives

The individual fitness constituent functions described in Section 1.6.2 are defined such that all values are bounded by 0 and 1. In the funding proposal it was stated that the objectives would be given various weightings depending on their importance as determined from irrigation authority personnel who are responsible for managing the delivery of irrigation water. It was decided

by G–MW personnel that the weight specification was, in fact, to be variable, and that different weightings reflecting the relative importance of the various objectives be tested using the GA methodology. The total fitness of any order schedule is thus given by the weighted sum of the fitness constituents (A)–(F) described in Section 1.6.2, where the weighting is user-specified. This is then multiplied by 100 to give an overall fitness value which represents the "pseudo-percentage" of the theoretical maximum achievable value.

2 Statement of Results

The research examined the use of GA optimisation to identify water delivery schedules that achieve the best possible outcomes for a set of objectives, while satisfying a set of constraints. The identification of significant objectives and important constraints was a major research outcome. The development of suitable representations of these factors for incorporation within the GA framework was another. For the idealised system of five irrigators on a channel spur, it was determined that the GA efficiently identified the known optimal schedule for the simple irrigation order optimisation problem. Integration of the GA software with Rubicon's IPM software, by developing an appropriate API layer, enabled the use of G–MW's Tatura data to generate results of more general interest. These results have shown great promise in the ability of GA techniques to determine irrigation order schedules that are good first approximations suitable for investigation. The intention is that these schedules will be reviewed and finalised by irrigation planners, and then implemented by field operators.

The most significant outcome of this research, as stated in the grant proposal (Dandy and Simpson, 1996a), is a methodology for applying GA techniques to the optimal scheduling of irrigation orders in open-channel systems. The methodology is implementable via a new GA software module that can be used with the existing IPM water ordering, planning, and management software.

In the funding proposal it was stated that the task of the irrigation planners would be greatly assisted by this module, although they would still have the capacity to override suggestions for shifting an irrigation order backward or forward in time. At present there is no mechanism in the API between the GA and IPM software layers to either "save" a plan for scheduling irrigation orders on the Tatura area network to the G–MW database nor, subsequently, to allow the planner to override schedules optimised by the GA technique. As proposed in a submitted funding grant application (Simpson et al., 1999a), it is intended to implement these two tasks, and others, as part of further refinements to, and field testing of, the GA optimisation process.

2.1 Interpretation of Results

The results of this "evaluation of the applicability of GA technology to flow management of open-channel gravity systems" have shown that the technology can efficiently schedule irrigation order requests.

They have also shown that further research, development, and field testing is required before the techniques are refined to a form where they can be properly applied to a real system. This is proposed in a submitted funding grant proposal (Simpson et al., 1999a). A detailed assessment of the benefits and costs of implementing the system in the everyday working environment of a water authority would, at that stage, be possible. This is also proposed in the recently submitted application.

2.2 Practical Significance of Results

It has been shown that irrigation order schedules can be optimised using GA techniques. Whether it is economically, philosophically, and/or practically viable for irrigation authorities to implement these techniques into their day to day operations remains to be determined in the new research project proposed (Simpson et al., 1999a).

2.2.1 Order Linking

Using the IPM interface, the G–MW irrigation planners schedule each order by linking the end of one (finishing) order with the beginning of a suitable (starting) order. The choices that are possible in specifying the linking of orders in fact constitutes the scheduling process, as performed by "human" planners.

Using GA optimisation, however, the scheduling process of the "computer" does not require order linking and is, in effect, achieved by considering all orders at once, as opposed to one order at a time. This is one of the major advantages of the GA optimisation approach. The disadvantage,

on the other hand, is that at the end of the optimisation, the GA technique provides no information as to which starting order conceptually "follows" a particular finishing order. If the planner wishes to adjust, for whatever reason, one finishing order with respect to that suggested by the GA process, it is logical that the planner would also wish to know what starting order this might affect. This information would not be available to the planner evaluating a schedule optimised by the GA unless appropriate links were also defined as part of the optimisation process. At present they are not.

Thus, a key component of a proposed new research project (Simpson et al., 1999a) is to develop of an "order linking" algorithm, since the representation of links between irrigation orders finished and those started is required by the G–MW irrigation planners and is also required to be represented in the IPM interface.

2.3 Comparison of Results against Project Objectives

The following sections compare the research results obtained against the proposed project objectives.

2.3.1 Project Objectives

In the funding proposal (Dandy and Simpson, 1996a) the project objectives were stated thusly.

1. To evaluate the applicability of GA optimisation to improving scheduling and delivery of irrigation flows via open-channel gravity systems.

2. To determine what objectives are important in delivering irrigation water by interviewing personnel in irrigation authorities.

3. To apply the methodology to a case study open-channel flow delivery system for the Tatura irrigation area of G–MW in Victoria.

4. To determine the cost savings arising from implementation of optimisation within computerised irrigation ordering techniques.

The optimisation objectives discussed in project objective 2 were determined in the manner proposed. The GA methodology discussed in project objective 3 was then applied to the system proposed. The GA optimisation technique was subsequently shown to be applicable to the scheduling described in project objective 1. The benefits and costs discussed in project objective 4 were then determined (Nixon et al., 1999a), in so far as was possible (see Section 2.3.2).

2.3.2 Alteration to Original Objectives

The only alteration to the proposed objectives of Section 2.3.1 is that the benefit cost analysis described in project objective 4 could only be carried out using estimated actual benefit and cost evaluations. The reasons for this objective alteration are discussed in Section 2.1.

3 Adoption Activities

The following sections outline how the research can be adopted and summarise the communication, technology transfer, and "adoption" activities carried out to date.

3.1 Adoption Strategies Outline

At it's final meeting, the project Steering Committee voted unanimously to submit a full proposal for National Program for Irrigation Research and Development (NPIRD) funding to continue the research in 1999–2001 (Simpson et al., 1999a), following the success of a preliminary proposal (Simpson et al., 1999b). The present project has shown that the GA is able to determine irrigation order schedules which, qualitatively, satisfy the constraints and achieve the objectives specified by G–MW to be most important. In the next project, it is proposed to trial the GA technique—in parallel with G–MW planners at the Tatura offices—on orders over a period of time, to investigate the quantitative differences in scheduling outcomes between the "computer" and "human" generated plans.

It is fully expected that, after the proposed further research, a detailed understanding of how the application of GA techniques to irrigation order scheduling can be adopted into everyday planning activities—of water authorities using the IPM system—will result.

3.2 Adoption Activities Summary

In the following summary of communication, technology transfer, and "adoption" activities to date, the activities are listed in approximate chronological order, where appropriate.

Two periodical articles which described the basic assumptions, general methods, and expected outcomes of the project were published at the commencement of project funding (Dandy and Simpson, 1996b; Edge, 1997).

A pamphlet describing this research for non-technical audiences (Nixon et al., 1997a) was produced during the initial stages of the project. It has been widely distributed to irrigation and water resources conference delegates, and to representatives of the corresponding industry and government bodies.

At the inaugural Steering Committee meeting, in Adelaide, proposed methods and expected outcomes were presented (Dandy, 1997; Simpson, 1997; Nixon, 1997d,a), and related discussions ensued (Nixon, 1997c,b).

At the penultimate Steering Committee meeting, in Tatura, methods and results were presented (Nixon, 1998e), and related discussions ensued (Nixon, 1998d).

At the Department of Civil and Environmental Engineering of The University of Adelaide, following presentations of methods and results (Nixon, 1999d), discussions were held with representatives of Goulburn–Murray Water and Rubicon Systems Australia Pty Ltd (Nixon, 1999f).

At the final Steering Committee meeting, in Tatura, summaries of methods and results, and avenues of future research were presented (Nixon, 1999g), and related discussions ensued (Nixon, 1999e).

Two papers were presented at Australian National Committee on Irrigation and Drainage (ANCID) conferences, and subsequently published in the respective proceedings (Dandy et al., 1997; Nixon et al., 1998c).

At the G–MW Tatura offices, following presentations of methods and results (Nixon, 1998c, 1999h), two workshops were held (Nixon, 1998b, 1999f). It is intended to conduct a further workshop in conjunction with the ANCID conference of 25–27 October 1999.

Two articles to be submitted to American Society of Civil Engineers (ASCE) journals are in preparation.

4 Publications Titles

The following sections list the titles of publications associated with this project.

4.1 Conference Proceedings

Improved Scheduling of Irrigation Deliveries Using Genetic Algorithms (Dandy et al., 1997)
Genetic Algorithm Optimisation Applied to Open-Channel Irrigation Flow Management (Nixon et al., 1998c)

4.2 Technical Manuals

Genetic Algorithm Optimisation Software in Fortran 90 (Nixon, 1999c)
An Evaluation of the Applicability of Genetic Algorithm Technology to Flow Management of Open-Channel Gravity Systems (Nixon, 1999a)

4.3 Pamphlets

An Evaluation of the Applicability of Genetic Algorithm Technology to Flow Management of Open-Channel Gravity Systems (Nixon et al., 1997a)

5 Additional Information

The reader can obtain additional information, if required, by contacting the Principal Investigators associated with the UAD14 project. Contact details are listed on the title page to this report.

A three-fold A4 colour pamphlet describing this research for non-technical audiences (Nixon et al., 1997a) is also available on request.

Supporting Documents

The following works are attached and listed in the References on pages III–IV. They represent a complete set of the technical reports, journal articles, conference/workshop papers, other publications, and other forms of information which describe in detail the technical results of this project. They are listed in approximate chronological order.

1. Steering Committee Meeting Presentation [26/6/97]: **LWRRDC R&D Project UAD14: An Evaluation of the Applicability of Genetic Algorithm Technology to Flow Management of Open-Channel Gravity Systems** (Dandy, 1997)
2. Steering Committee Meeting Presentation [26/6/97]: **Genetic Algorithm Optimisation** (Simpson, 1997)
3. Steering Committee Meeting Presentation [26/6/97]: **Progress to Date—LWRRDC Project UAD14—Steering Committee Meeting Number 1** (Nixon, 1997d)
4. The GA Objectives [26/6/97]: **The GA Objectives** (Nixon, 1997a)
5. Steering Committee Meeting Minutes [29/7/97]: **Meeting of Steering Committee for LWRRDC Project UAD14** (Nixon, 1997c)
6. The GA Objectives [27/6/97]: **The GA Objectives** (Nixon, 1997b)
7. Pamphlet [1/9/97]: **An Evaluation of the Applicability of Genetic Algorithm Technology to Flow Management of Open-Channel Gravity Systems** (Nixon et al., 1997a)
8. Conference Paper [4/9/97]: **Improved Scheduling of Irrigation Deliveries Using Genetic Algorithms** (Dandy et al., 1997)
9. Technical Report [24/10/97]: **LWRRDC Project UAD14—"An Evaluation of the Applicability of Genetic Algorithm Technology to Flow Management of Open-Channel Gravity Systems"—Progress Report to October 24, 1997** (Nixon et al., 1997b).
10. Steering Committee Teleconference Minutes [12/11/97]: **The 97/01 Telephone Conference** (Nixon and Simpson, 1997)
11. Technical Report [15/4/98]: **LWRRDC Project UAD14—"An Evaluation of the Applicability of Genetic Algorithm Technology to Flow Management of Open-Channel Gravity Systems"—Progress Report 2: April 15, 1998** (Nixon et al., 1998a).
12. Conference Paper [5/8/98]: **Genetic Algorithm Optimisation Applied to Open-Channel Irrigation Flow Management** (Nixon et al., 1998c).
13. Technical Report [6/11/98]: **LWRRDC Project UAD14—"An Evaluation of the Applicability of Genetic Algorithm Technology to Flow Management of Open-Channel Gravity Systems"—Progress Report 3: November 6, 1998** (Nixon et al., 1998b).
14. Goulburn–Murray Water Personnel Workshop Presentation [16/11/98]: **LWRRDC Project UAD14—Land and Water Resources Research and Development Corporation—"An Evaluation of the Applicability of Genetic Algorithm Technology to Flow Management of Open-Channel Gravity Systems"** (Nixon, 1998c).
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