Water allocation planning in the Indus Basin Irrigation System in Pakistan: Using scientific tools to build trust between stakeholders

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Abstract: Pakistan manages the world's largest contiguous irrigation system, the Indus Basin Irrigation System (IBIS). This system, which is under increasing pressure from population growth and climate change, provides water, energy and food security for the nation. The Indus River System Authority (IRSA) in consultation with the Water and Power Development Authority (WAPDA) and Provincial Irrigation Departments share the surface water resources of the IBIS between the four provinces of Pakistan. They distribute this resource for irrigation, urban, stock and domestic and industrial use as well as generating electricity as the waters travel through the system. Broad principles on how the water resource is to be allocated is described in a 1991 Inter-Provincial Water Apportionment Accord. However, how these principles are interpreted and implemented is a detailed, complex process that is understood by only a few experts. With an aim to capture this knowledge and in so doing provide a transparent, neutral and consistent process, CSIRO has developed the Water Apportionment Accord (WAA) Tool (Ahmad et al., 2022). This Tool replicates the 6 steps in the pre-season (Kharif and Rabi) forecasting and subsequent 10-day allocation process of the IBIS. Building understanding was achieved from many conversations over multi-year planning sessions to distil and document the process. This understanding was then translated using water resources management (WRM) and irrigation management concepts into mathematical formulations which were packaged into the WAA Tool. This process was informed by being provided with a set of complex spreadsheets within IRSA. The processes as captured in the Tool continue to be tested and refined through detailed checking and cross-checking against the manual methods being used. While CSIRO coded the Tool using modern software practices and interface style, the Tool was co-designed to respect the manual processes and preferences being used through, as far as possible, mimicking the way planning and reporting of outcomes were being done. The Tool even includes the ability to generate Rabi and Kharif Year Books, very similar to those produced manually. This joint and iterative collaboration between CSIRO and our water agency staff has been important as while the automation of key parts of the seasonal water planning procedure has brought much-needed innovation and modernization to the planning process, it is new and has had to prove itself. The Tool has uplifted IRSA in its seasonal water anticipation/forecasting to such an extent that they can now easily explore different scenarios of water availability for their better understanding and, accordingly, IRSA's distribution and regulation of water shares in accordance with the 1991 Water Apportionment Accord. The Tool has not only provided IRSA with quick access to probable scenarios of water planning but has also solidified the confidence, harmony and trust amongst the federating units / stakeholders in terms of the transparency of water availability and its regulation/distribution. IRSA and provincial water agencies have been trained in using the Tool and they actively participate in its testing and development. In addition, CSIRO has prepared extensive training material, including user guide and reference manual (Ahmad et al., 2022) and run many on-the-job training workshops. This material can be useful for educational institutions in their training of the next generation of water professionals in Pakistan.

Keywords: *Water allocation, water distribution, irrigation, river basin management, water negotiations*

1. INTRODUCTION

Pakistan operates the world's largest contiguous irrigation system, the Indus Basin Irrigation System (IBIS), which supports food production, energy generation and stock, domestic and industrial supply for the nation (Briscoe et al., 2005). As shown in Figure 1, the IBIS is located in the lower Indus plain and spans the 4 provinces of Pakistan. This system is predominantly dependent on surface water supplies from the mountainous part of the upper Indus Basin; therefore, fair sharing of this water is critical for all provinces (Ahmad et al., 2021; Podger et al., 2021).

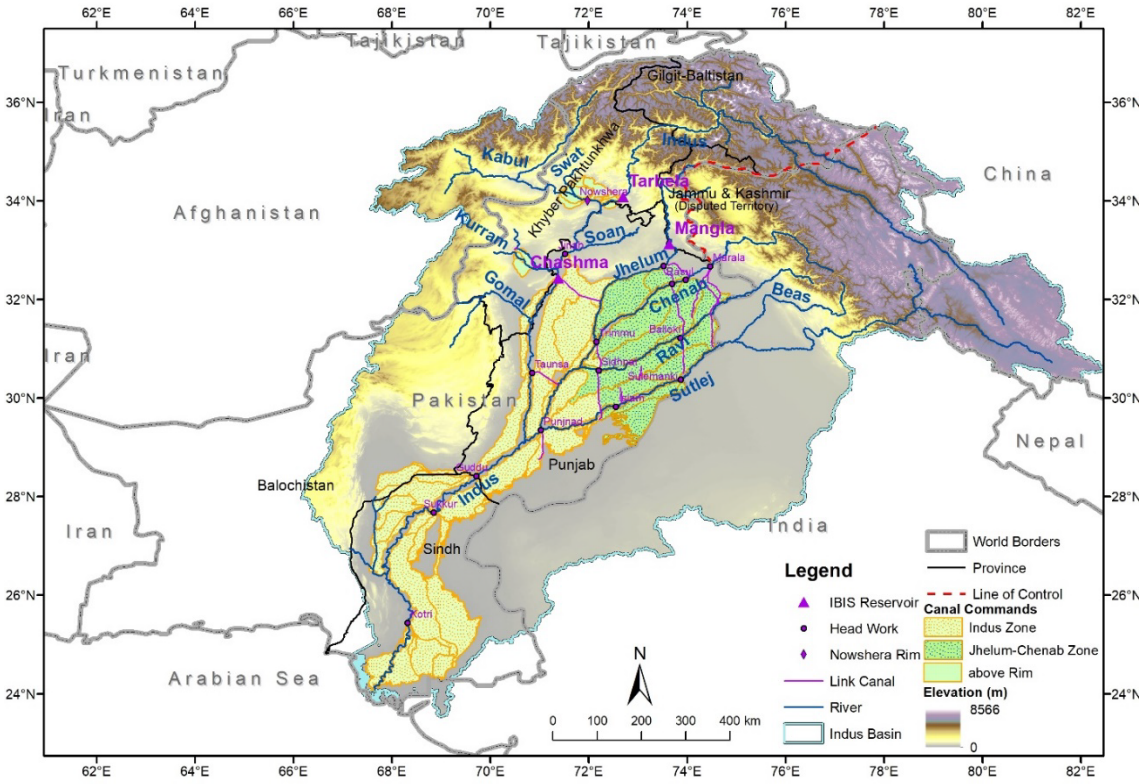


Figure 1. The Indus River System showing major dams, headworks, provincial boundaries, canal commands and the Indus and Jhelum Chenab sub-systems (zones) of the Indus Basin Irrigation System

The headwaters of many of the rivers feeding into the IBIS are in neighbouring countries – the Tibetan plateau in China to the north, the Himalayas in India to the east, and the Paghnam Range in Afghanistan to the west. The 1960 Indus Waters Treaty (IWT) between India and Pakistan (United Nations, 1960) granted full access to the waters of the three eastern rivers (Ravi, Beas and Sutlej) to India, and since then flows from these rivers into Pakistan have substantially reduced over time as India develops its water resources in these rivers.

Within Pakistan, after the 1947 separation (of Pakistan from India), the Pakistan surface water resource was allocated to the four provinces of Pakistan – Punjab, Sindh, Khyber Pakhtunkhwa (KP) and Balochistan – on an informal basis. However, as provinces continued to develop their irrigation areas, access to the resource became increasingly contested. To manage this, the provinces negotiated a sharing arrangement known as the 1991 Water Apportionment Accord (the Accord). The Accord describes broad water-sharing principles in 14 paragraphs and 8 appendices (Government of Pakistan, 1991). The Accord is a consensus document signed by the Provinces and ratified by the Prime Minister; however it is not constituted under any Act of Parliament. The Accord is still in operation and has largely remained unchanged.

The Government of Pakistan established the Indus River System Authority (IRSA) in 1992 to manage the regulation and monitoring of the distribution of water resources of the Indus River in accordance with the Accord. IRSA has representation from all four provinces and the federal government. The chair of IRSA is rotated each year between each of the representatives. The lack of detail within the Accord and its non-legal status make the practical implementation of the Accord difficult as IRSA and the provinces interpret how to operationalise the Accord sharing principles differently, resulting in mistrust and disputes.

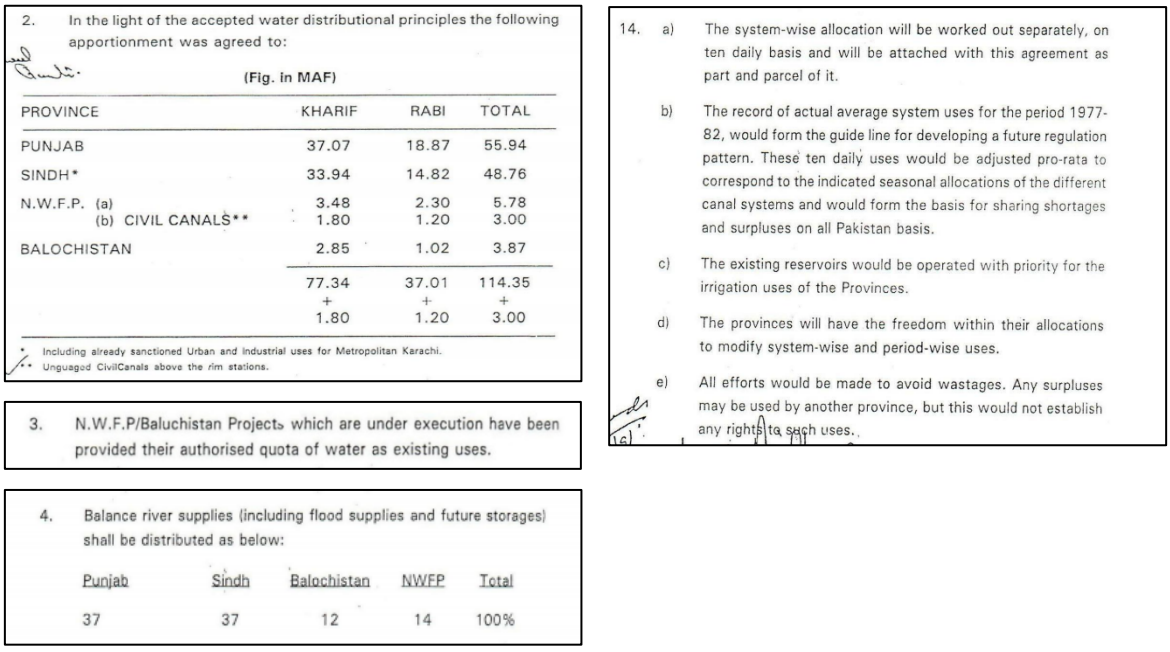
The Friends of Democratic Pakistan report (FODP-WSTF, 2012) has stated that 'improving the implementation of the 1991 Water Accord is the first institutional measure to take to reduce conflict over much-needed major water infrastructure.' The 2019 World Bank report (Young et al., 2019) also highlights the water security issues that Pakistan faces and calls for a need to be able to accurately and transparently model the water sharing arrangements in response to changing resource availability, growth in demand from competing users and loss of storage capacity through sedimentation. Heeding these calls for action, the Australian Government through its Department of Foreign Affairs and Trade (DFAT), the Australian Centre for International Agricultural Research (ACIAR) and CSIRO initiated a project to develop a scientific tool to bring transparency and consistency in inter-provincial water allocation decision making in Pakistan. This tool is called the Water Apportionment Accord (WAA) Tool. This paper describes how the Accord is implemented in practice and how the human dimension of developing the WAA Tool was navigated.

1.1. 1991 Inter-Provincial Water Apportionment Accord

The Accord has 14 clauses ('Paragraph' in the Accord) that broadly describe how the Indus (surface) water resources are to be shared between the 4 provinces of Punjab, Sindh, Khyber Pakhtunkhwa (KP) and Balochistan on a seasonal basis. There are two seasons: Kharif (April-September) and Rabi (October-March). The Kharif season is further sub-divided into early Kharif (1/4-10/6) and late Kharif (11/6-30/9). Four of the Paragraphs are relevant to the sharing arrangements – Paragraphs 2, 3, 4 and 14(b) (Figure 3).

- Paragraph 2 considers accepted water distributional principles under current storage capacity
- Paragraph 3 establishes that the authorised quotas of water for KP and Balochistan projects that were under execution at the time of the signing of the Accord be considered as existing uses
- Paragraph 4 is used to balance river supplies above Paragraph 2 from floods and future storages
- Paragraph 14 sub-clause b [14(b)] is used to establish the pattern of regulation based on observed average system uses for the period 1977–82.

The Accord does not include values for Para 14(b). Values (in Million Acre Feet MAF) as an average of observed annual system use for the period 1977–1982 are given in Table 1. These are taken from Khan (2016).



2. In the light of the accepted water distributional principles the following apportionment was agreed to:

(Fig. in MAF)

PROVINCE	KHARIF	RABI	TOTAL
PUNJAB	37.07	18.87	55.94
SINDH*	33.94	14.82	48.76
N.W.F.P. (a)	3.48	2.30	5.78
(b) CIVIL CANALS**	1.80	1.20	3.00
BALOCHISTAN	2.85	1.02	3.87
	77.34	37.01	114.35
	+	+	+
	1.80	1.20	3.00

* Including already sanctioned Urban and Industrial uses for Metropolitan Karachi.
** Unguaged CivilCanals above the rim stations.

3. N.W.F.P/Baluchistan Projects which are under execution have been provided their authorised quota of water as existing uses.

4. Balance river supplies (including flood supplies and future storages) shall be distributed as below:

Punjab	Sindh	Balochistan	NWFP	Total
37	37	12	14	100%

14. a) The system-wise allocation will be worked out separately, on ten daily basis and will be attached with this agreement as part and parcel of it.

b) The record of actual average system uses for the period 1977-82, would form the guide line for developing a future regulation pattern. These ten daily uses would be adjusted pro-rata to correspond to the indicated seasonal allocations of the different canal systems and would form the basis for sharing shortages and surpluses on all Pakistan basis.

c) The existing reservoirs would be operated with priority for the irrigation uses of the Provinces.

d) The provinces will have the freedom within their allocations to modify system-wise and period-wise uses.

e) All efforts would be made to avoid wastages. Any surpluses may be used by another province, but this would not establish any rights to such uses.

Figure 3. Paras 2, 3, 4 and 14 from the Accord document (extracted from Government of Pakistan (1991))

Table 1. Para 14(b) average of observed annual system use for the period 1977–82 (Khan 2016). Current values are used in the WAA Tool for KP and Balochistan (see notes below)

Province	Kharif (MAF)	Rabi (MAF)	Total (MAF)
Punjab	34.66	19.85	54.51
Sindh*	28.55	14.98	43.53
KP (a)	1.80	1.27	***3.06
(b) Civil canals**	1.75	0.73	2.49
Balochistan	0.85	0.78	***1.63
Total (below rim stations without civil canals)	65.86	36.87	102.74
Total (below rim stations and with ungauged civil canals above rim stations)	67.61	37.60	105.23

* includes already sanctioned urban and industrial uses of Metropolitan Karachi
** ungauged Civil canals above rim stations
*** The KP and Balochistan 10-day share constraints sum to less than their seasonal shares. Consequently, as these provinces develop their ability to consume their seasonal share, these constraints are adjusted accordingly. The 2020–21 annual share for KP was 1.52 MAF: 0.82 MAF in Kharif and 0.70 MAF in Rabi whereas Balochistan share was 3.87 MAF: 2.85 MAF in Kharif and 1.02 MAF in Rabi.

2. WATER ALLOCATION DECISION MAKING

Due to the structural layout of the IBIS not all users have access to the supply reservoirs. For this reason, the allocation process is further subdivided into two systems (zone): Indus and Jhelum-Chenab (Figure 1). The Indus system provides water to all four provinces while the Jhelum-Chenab system only supplies water to Punjab but through end of system flows can provide water to Sindh and Balochistan. The allocation process tries to balance shortfalls between these two systems by managing outflows out of the Jhelum-Chenab system. An animated version of the schematic diagram of 10-day water allocation process showing how water is shared across the J-C and Indus systems is available at https://www.youtube.com/watch?v=9pK4LG2IYcc.

The Accord does not explicitly define how water is to be shared on a 10-day basis, however, it does provide broad guidance under Para 14(b) on 10-day future regulating pattern and required adjustments to allow shortages and surpluses on an all-of-Pakistan basis. Para 14(d) also provides freedom to provinces to modify system-wise and period-wise uses while staying within their allocations (Government of Pakistan, 1991).

The water sharing process can be split into 6 steps that control the process. These are listed here and laid out in Figure 3.

- Step 1 Forecast 10-day rim station inflows
- Step 2 Calculate last 5 years of losses and gain
- Step 3 Maintain reservoirs between maximum and minimum 10-day storage level targets while considering:
  - Step 3.1 anticipated targets
  - Step 3.2 dam filling safety criteria and minimum releases from reservoirs
  - Step 3.3 equity of access to water resource
  - Step 3.4 below Kotri flows
- Step 4 Harmonise operation of Tarbela and Mangla reservoirs across 10-day periods
- Step 5 Balance resources between Jhelum-Chenab and Indus systems
- Step 6 Balance and share shortages between provinces across time.

A high-level description of these steps is given in Ahmad et al. (2022).

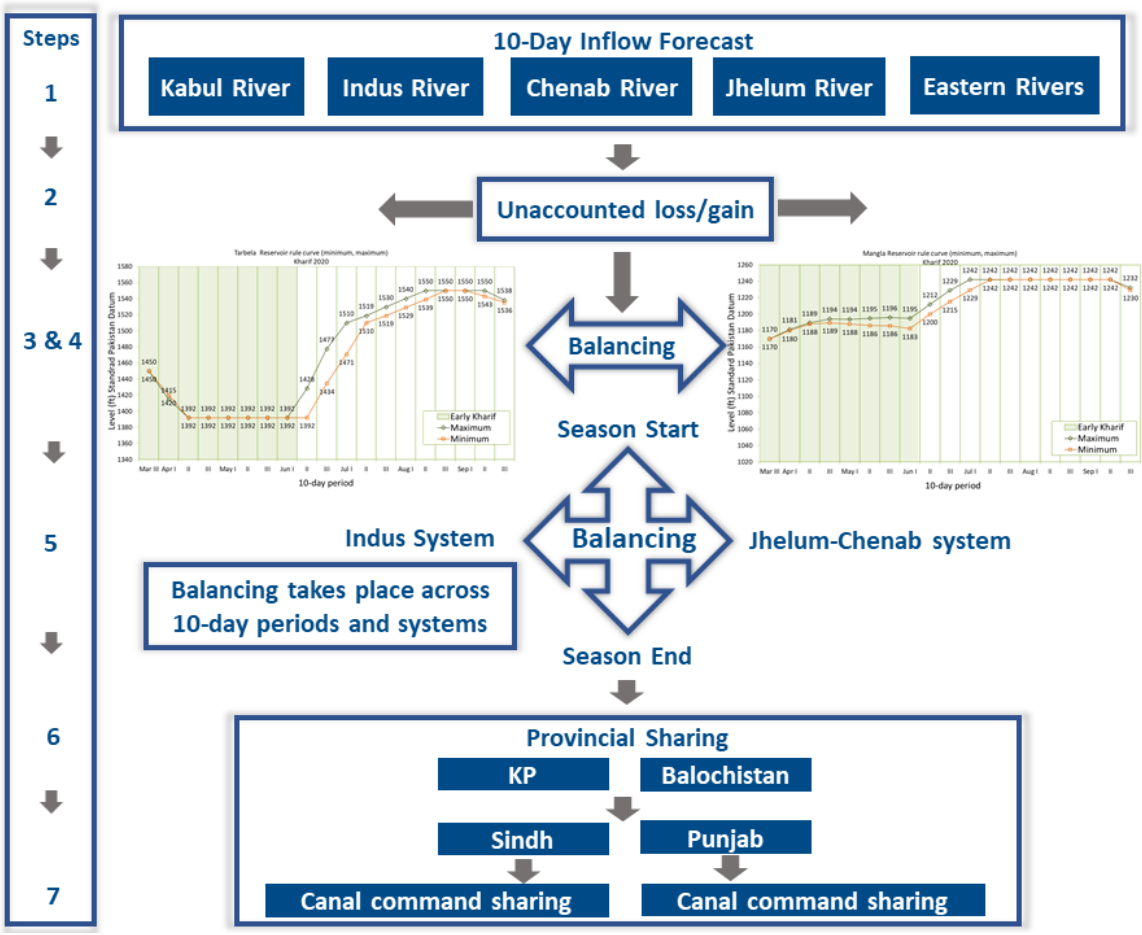


Figure 3. Schematic of the 6 steps in the allocation process in the IBIS
(Step 7 refers to sharing at Canal command level. Sharing at this level is undertaken within each province and is not included in the WAA Tool implementation)

3. DIFFERENT INTERPRETATIONS FOR SHORTAGE SHARING BETWEEN PROVINCES

There are two areas of interpretation that have caused some tension, the priority of sharing of water between provinces and the 3 Tier formula (as described in Khan, 2011). The current sharing arrangement is to share water first to KP and Balochistan and then share the remaining resource between Punjab and Sindh. This arrangement reflects the difference in the ability of provinces to utilise their share. Historically KP and Balochistan were less developed than Punjab and Sindh and could not utilise all their allocation. To allow for this they were granted higher priority access and any under-utilisation was subsequently available to Punjab and Sindh. However, over time Balochistan and to a lesser extent KP have developed up their irrigation systems. Balochistan is now at a point whereby it can consume most of its resource. Consequently, Sindh is asking if it is appropriate to continue this arrangement. The Accord makes no specific mention of this sharing arrangement.

The 3-tier approach is based on different sharing ratios between provinces as a function of the available resource. There are three levels of increasing resource; Paragraph 14b, Paragraph 2 and Paragraph 4. The current interpretation is for resources up to the Paragraph 14b resource are shared according to Paragraph 14b. For resource above the Paragraph 14b resource is shared according to Paragraph 2. Resource beyond Paragraph 2 is rare, but when this occurs, this additional resource can be shared according to Paragraph 4. An alternate interpretation of this rule is to share everything according to Paragraph 2 and any excess according to Paragraph 4. Under the current hierarchy of sharing this only affects Punjab and Sindh as the other provinces are allocated up to their maximum level of take prior to 3-tier sharing. The Accord does not explicitly describe the 3-tier sharing arrangement and this practice has been contested.

4. SUPPORTING DECISION MAKING

The WAA Tool is broadly based on the water sharing principles that are described in the Accord. It captures documented and undocumented procedures; and provides transparency and consistency in the seasonal water allocation process such that the process is repeatable by all stakeholders. It allows users to explore alternate system operational rules so that the effect of using different rules can be compared and contrasted.

The WAA Tool supports the current seasonal water allocation process through allowing users to:

- evaluate the performance of other seasonal forecasting methodologies in comparison to existing statistical (probability table) method
- examine different interpretations of how shortages are shared between provinces i.e. between Para 14(b), 2 and 3 Tier method
- assess the impact of different provincial shortage sharing options: (i) Punjab and Sindh, (ii) Punjab, Sindh and Balochistan, (iii) All provinces
- option to distribute equal percent shortages on 10-day or seasonal basis to provinces
- look into different filling rates for Tarbela
- explore different storage targets and storage carryover into the next season
- configure equalisation across 10-day periods (if this option is selected)
- manage datasets in a way that guarantees their integrity
- update 10-day observed flow data over multiple seasons and years
- simplify report generation steps: export a report as a printable Excel (.xlsx) workbook by default. The workbook records all of the critical information from a session, i.e. selected parameters and manual entries, for future reference.

In addition to this flexibility, it is possible to modify level-volume relationships for the supply reservoirs to investigate impacts of sedimentation on resource sharing.

5. SUMMARY AND CONCLUSION

Through extensive consultation with Pakistan water jurisdictions, this study has quantified the rules and methods both documented and undocumented that are used in the Pakistan seasonal resource assessments. It has captured this within a tool that can accurately reproduce the probabilistic inflow forecasts and replicate the different variations of the resource assessment.

The WAA Tool addresses several technical and transparency issues. Previously the water allocation process took skilled operators' days to allocate the resource. This can now be done in seconds. This provides a means to rapidly assess different options and game the allocation process. As the tool uses an iterative solver it can more accurately solve the temporal and spatial distribution of water within the constraints much more accurately than the manual process and thus be more efficient in the sharing of water.

The tool solves a major transparency problem between provinces. The tool provides a consistent database and methodology that ensures that IRSA and provincial managers will get the same answer for the same configuration. Historically this has not been the case which has caused mistrust.

The tool has been used to understand the implications of adopting 3 Tier or paragraph 2 sharing as well as the implication of providing high security water to KP and Balochistan.

The unbiased, open and collegiate manner in which the Tool has been developed has built trust in the Tool – all voices have been heard and all interpretations of the Accord implemented. Trust is hard to gain and easy to lose – taking things slowly and surely, documenting processes and seeking confirmation that processes have been accurately recorded and implemented, careful dialogue and even-handed behaviour (i.e. all views are legitimate and all parties are equal) have been critical factors in progress to date. The human dimension of the Tool development has been the most challenging, and the most rewarding.

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