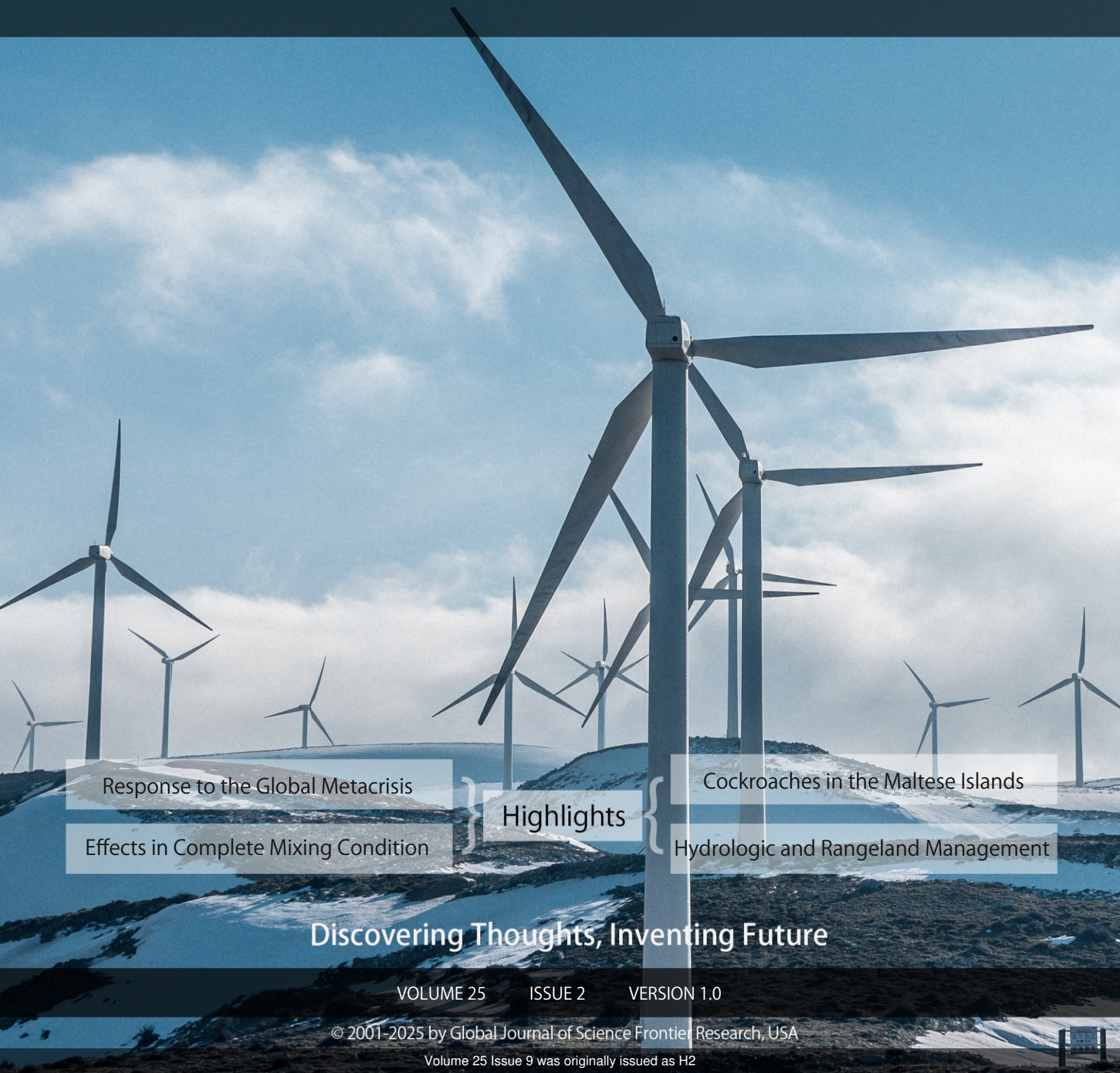
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Response to the Global Metacrisis

Effects in Complete Mixing Condition

Highlights

Cockroaches in the Maltese Islands

Hydrologic and Rangeland Management

Discovering Thoughts, Inventing Future

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By Wendy Ellyatt

Abstract- This paper presents a reflective condensation of the 2025 White Paper commissionedfor the three year Galileo Commission Worldviews Study. This explored the emergence of a Unitive Worldview and Narrative as an integrative response to the metacrisis-a convergence of ecological, social, epistemic, and existential breakdowns facing humanity. Building on the legacy of the Integrative Worldview suggestion that was explored in Year One, the paper sought to advance the discussion by weaving together insights from developmental psychology, systems thinking, Indigenous cosmologies, spiritual philosophy, quantum science, and regenerative design. It proposed that the Unitive Worldview represents an evolutionary synthesis: one that transcends fragmentation and dualism by recognizing the relational, participatory, and co-creative nature of reality. Within this frame, flourishing is not merely an individual or material pursuit, but a systemic condition rooted in coherence-between self and other, society and ecology, inner life and outer systems.

Keywords: *metacrisis, integrative, regenerative, flourishing, ecology, education, ethics, future generations.*

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Toward a Unitive Narrative and Worldview: An Integrative Response to the Global Metacrisis

Wendy Ellyatt

Abstract- This paper presents a reflective condensation of the 2025 White Paper commissionedfor the three year Galileo Commission Worldviews Study. This explored the emergence of a Unitive Worldview and Narrative as an integrative response to the metacrisis—a convergence of ecological, social, epistemic, and existential breakdowns facing humanity. Building on the legacy of the Integrative Worldview suggestion that was explored in Year One, the paper sought to advance the discussion by weaving together insights from developmental psychology, systems thinking, Indigenous cosmologies, spiritual philosophy, quantum science, and regenerative design. It proposed that the Unitive Worldview represents an evolutionary synthesis: one that transcends fragmentation and dualism by recognizing the relational, participatory, and co-creative nature of reality. Within this frame, flourishing is not merely an individual or material pursuit, but a systemic condition rooted in coherence—between self and other, society and ecology, inner life and outer systems. Eco-systemic flourishing is presented as a practical expression of this worldview shift, offering a values-based, developmentally grounded, and context-sensitive model for measuring and cultivating wellbeing across generations and cultures. By aligning ontology, ethics, education, and governance with the principles of interbeing and interdependence, the Unitive Worldview offers a compass for regenerating human and planetary systems.

Keywords: metacrisis, integrative, regenerative, flourishing, ecology, education, ethics, future generations.

I. Introduction: The Metacrisis as a Worldview Challenge

In an era of unprecedented complexity and transformation, five interrelated global crises highlight the urgency of adopting a more integrative worldview—one that transcends outdated paradigms and fosters a holistic, adaptive approach to the challenges of the 21st century. Technological disruption is rapidly reshaping economies, labour markets, and governance through artificial intelligence, automation, and digital realities, raising pressing questions about the future of work and societal structures (Brynjolfsson & McAfee, 2014; Ford, 2015). At the same time, ecological collapse, driven by climate change and biodiversity loss, poses existential threats to planetary survival, necessitating urgent systemic change (IPBES, 2019; IPCC, 2022). Alongside these environmental and technological shifts, geopolitical fragmentation—marked by rising authoritarianism, economic inequality, and the erosion of democratic institutions—fuels global instability and polarization (Fukuyama, 2018; Mounk, 2018).

Compounding these crises is a meaning crisis, wherein the collapse of shared values and social disconnection leads to widespread existential uncertainty and disengagement (Putnam, 2000; Taylor, 2007). Finally, the proliferation of hyperreality and information warfare, driven by misinformation and the manipulation of subjective truths, has further eroded public trust in science, governance, and collective decision-making (Baudrillard, 1994; O'Connor & Weatherall, 2019). These crises, though distinct in their manifestations, are deeply interconnected, reinforcing the need for an epistemological and cultural shift toward a more holistic, relational and systems-based approach to global problem-solving. Only by integrating scientific materialism, wisdom traditions, and participatory governance can humanity navigate these profound challenges and co-create a more resilient and sustainable future. Our worldviews—our cognitive, social, and metaphysical lenses—directly influences decision-making, policy, and societal structures. The limitations of reductionist materialism have contributed to environmental destruction and social alienation. Conversely, purely intuitive/spiritual perspectives often lack empirical grounding. An Integrative Worldview reconciles these extremes, offering a more complete epistemology for understanding and navigating complexity (Ellyatt, 2024). Worldviews are not merely abstract philosophical constructs; they operate at the level of identity, morality, and institutional logic. They influence what counts as knowledge, how priorities are set, and how relationships—between humans, nature, and technology—are conceived. The dominant worldview of the modern industrial era, often termed 'reductionist materialism,' privileges objectivity, control, and individualism. It sees the world as a machine, life as a resource, and progress as linear. This paradigm, while powerful in enabling scientific and technological development, is increasingly recognized as inadequate for navigating the entangled, multi-scalar challenges of the Anthropocene (Capra & Luisi, 2014). Alternative worldviews have long existed alongside dominant paradigms. Indigenous cosmologies, Eastern philosophies, and holistic systems thinkers have articulated relational, cyclical, and participatory understandings of reality. However, these perspectives have often been marginalized, suppressed, or treated

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as pre-modern. Today, many of their insights are being re-evaluated in light of complex systems science, quantum theory, and transpersonal psychology (Laszlo, 2004; Wilber, 2000). This re-evaluation signals the emergence of a new integrative paradigm—what some call a 'Unitive Narrative and Worldview'—which seeks to transcend dualisms and reconcile the inner and outer, spiritual and scientific, individual and collective.

In this paper, we propose that this is not only desirable but necessary. It offers a coherent frame for responding to the metacrisis at its root, by shifting the foundational assumptions that underpin human systems. Through a review of worldview evolution, we aim to demonstrate how such a shift can inform education, governance, and cultural transformation. Ultimately, we argue that the Unitive paradigm provides a compass for regenerating coherence across fractured systems—within ourselves, our societies, and the living Earth.

II. Methodology and Scope

This paper serves as a reflective synthesis of the Galileo Commission's Year 2 White Paper, which formed part of a three-year Worldviews Study examining the emergence of integrative paradigms in response to the global metacrisis. The methodology employed is primarily conceptual and metatheoretical, drawing upon a broad, multidisciplinary literature base rather than empirical or experimental data. It consolidates insights gathered through an extensive review of developmental psychology, systems science, Indigenous epistemologies, quantum theory, narrative studies, and spiritual philosophy. These were brought together in the original white paper through a process of thematic integration and worldview mapping. Rather than advocating for a specific model or framework, this paper distils the core patterns and propositions identified across those diverse domains—particularly the emergent features of what has been termed the Unitive Worldview. Among the frameworks discussed in the White Paper, the Eco-Systemic Flourishing (ESF) model was presented as one illustrative application of unitive principles. Other integrative contributions from spiritual, scientific, and civil society sources are also acknowledged and situated within the broader synthesis. The role of the arts is further expanded as an essential element.

The aim of this paper is to make accessible the central findings of the Galileo Worldviews Study for a scholarly audience, providing a clear conceptual foundation from which further empirical work, institutional innovation, and cultural discourse might proceed. Its orientation is heuristic rather than prescriptive—mapping the contours of a worldview in formation and inviting ongoing engagement across academic, policy, and community settings.

III. Evolutionary Perspectives on Worldview Development

Human worldviews evolve in both cultural and cognitive domains. Developmental psychologists and philosophers of mind have emphasized that worldview development is not static but unfolds in structured patterns that reflect growing cognitive complexity and moral awareness. Piaget's foundational work on cognitive stages laid the groundwork for understanding how human reasoning expands from concrete operational thinking to formal abstraction (1960). Vygotsky emphasized that human development is a social and cultural process, not solely an individual one (1978). And Kegan extended this trajectory into adulthood with his concept of self-authorship, describing how individuals gradually shift from being shaped by social systems to constructing and integrating their own values, identities, and perspectives (1994).

The Unitive Worldview emerges as a coherent synthesis at these higher stages. It is not simply an amalgamation of prior paradigms but an integrative epistemology that honors both differentiation and wholeness. It reflects a developmental readiness to hold paradox, navigate ambiguity, and synthesize diverse perspectives into coherent patterns. This worldview embraces relational intelligence, inner transformation, and participatory engagement as central to human maturity. Neuroscience also contributes to this understanding. Iain McGilchrist (2023) draws on hemispheric brain research to argue that Western culture has become excessively dominated by left-hemisphere, analytic modes of attention, which fragment reality into parts and emphasize control. In contrast, the right hemisphere's mode of knowing is contextual, relational, and integrative. McGilchrist suggests that healing our epistemic crisis requires restoring balance between these ways of knowing.

These developmental models show that worldview shifts are not simply ideological changes but transformations in perception, identity, and relational capacity. They are often catalyzed by crisis, dissonance, or spiritual insight. As individuals grow, they increasingly perceive themselves not as isolated agents, but as participants in interconnected systems—social, ecological, and cosmological.

Importantly, these worldview developments are not guaranteed. Many adults plateau at earlier stages due to social conditioning, trauma, or institutional constraints. Education systems, economic pressures, and cultural norms can reinforce egocentric or ethnocentric stages of development, limiting the emergence of integrative consciousness. Thus, facilitating worldview evolution requires intentional cultural, pedagogical, and policy interventions.

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Research from Indigenous epistemologies complements these developmental models. Rather than framing human maturation solely in terms of abstract reasoning, many traditional cultures emphasize relational responsibility, embeddedness in place, and spiritual coherence. For example, the Diné (Navajo) principle of Hózhó conveys a worldview centred on harmony, balance, and beauty (Kahn, J & Koithan, N 2015), values aligned with what developmental theorists might describe as integral consciousness. Integrating such traditions into global developmental discourse expands our understanding of what maturity entails. These educational insights align with practices such as dialogue circles, contemplative inquiry, and systems mapping that are increasingly being used to support worldview transformation across educational and organizational contexts. In this context, the Unitive Worldview should be understood not as an endpoint but as an emergent capacity—a living, dynamic orientation to life. It integrates the rational with the intuitive, the personal with the planetary, and the scientific with the sacred. Recognizing this potential across individuals and communities opens up possibilities for systemic transformation rooted in compassion, complexity literacy, and planetary care.

IV. The Influence of Language on Worldview Formation

Language is not simply a tool for communication; it is a foundational shaper of perception and thought. The Sapir-Whorf hypothesis posits that the grammatical structures and vocabularies of a language influence the cognitive patterns and cultural outlooks of its speakers (Whorf, 1956). Languages rich in verbs and relational syntax—such as many Indigenous and Eastern tongues—encourage a worldview grounded in interconnection, flow, and becoming. In contrast, Western Indo-European languages, with their emphasis on nouns and fixed categories, often reinforce dualism and objectification (Kimmerer, 2013). This linguistic distinction aligns with Alfred North Whitehead's critique of "the fallacy of misplaced concreteness," whereby abstract categories are treated as the fundamental units of reality, masking the primacy of dynamic processes (Whitehead, 1929). Robin Wall Kimmerer further illustrates this through Potawatomi grammar, which treats natural entities—rivers, rocks, trees—not as static objects but as animate relations, reshaping our ethical and ontological engagement with the world. The erosion of verb-rich relational language has, as Don Trent Jacobs (Four Arrows) argues, contributed to the dominance of objectifying and extractive worldviews, weakening our cognitive and emotional ties to the more-than-human world (Jacobs, 2006). Reclaiming these languages or adopting relational metaphors in education and public discourse may thus support what he calls "epistemic healing," reorienting consciousness toward interbeing and participatory ethics.

Mathematics, often celebrated for its precision and universality, is more than a neutral tool for quantification. It is also a symbolic language that encodes particular ontological and epistemological assumptions—assumptions that shape how we understand the world and our place within it. Classical Western mathematics developed within the worldview of Cartesian-Newtonian mechanics: a paradigm of separation, linear causality, and external control. It privileges static entities, reductionism, and measurement, reflecting a broader cultural commitment to objectivity and predictability. In this frame, nature becomes an equation to be solved, rather than a living system to be engaged. Yet mathematics is not monolithic. Within its depths lie other traditions—ancient, Indigenous, and emergent—that foreground relationship, flow, and transformation. As our planetary crisis reveals the limitations of mechanistic worldviews, mathematical thought itself is undergoing a quiet revolution. A number of influential mathematicians and systems theorists have contributed to the development of mathematical frameworks that reflect the dynamics of coherence, regeneration, and living systems. Robert Rosen pioneered relational biology by distinguishing living systems from mechanistic models through anticipatory systems theory (Rosen, 1991). Brian Goodwin applied nonlinear mathematics to morphogenesis, illustrating how patterns in biological development emerge from underlying generative principles (Goodwin, 1994). Similarly, D'Arcy Wentworth Thompson's early work in biological form revealed how growth processes follow geometrical and physical laws (Thompson, 1917). Louis Kauffman's explorations of recursive logic and self-reference in knot theory and cybernetics provide insights into the feedback dynamics of self-organising systems (Kauffman, 2001).

In the realm of theoretical physics, David Bohm's implicate order framed mathematics as a symbolic language for deep coherence and wholeness (Bohm, 1980). Meanwhile, Ilya Prigogine's work on dissipative structures demonstrated how open systems far from equilibrium can self-organise into new forms of order (Prigogine & Stengers, 1984). Contemporary advances in category theory, such as those of William Lawvere and Vladimir Voevodsky, offer abstract yet powerful tools for modelling relationships and transformations rather than static entities (Lawvere & Schanuel, 2009). Applied mathematicians like Nikos Salingaros have extended this thinking to architecture and urban design, formalising principles of spatial coherence and generative form (Salingaros, 2006). Together, these contributions support a shift from reductionist abstraction to relational mathematics aligned with the principles of life and regeneration. In sum, mathematics is not just about what we can

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calculate—it is about what we can *comprehend*. When it supports relational awareness, pattern resonance, and systemic integration, it becomes a vital ally in the emergence of a new planetary consciousness. Reframed through a Unitive lens, mathematical thinking no longer flattens the world into dead mechanism; it sings of a living, interconnected cosmos—one in which form, function, and flourishing are indivisible.

V. Key Features of the Unitive Worldview

a) Reality, under the Unitive Worldview, is Apprehended not as a Collection of Separate Entities Butas a Web of Becoming

Interactions that co-arise and co-constitute the world. Process philosophy and quantum mechanicsboth challenge the metaphysical assumptions of substance-based ontology. These perspectives align with Indigenous worldviews that treat land, ancestors, and ecosystems as sentient participants in relational life-worlds. For instance, the Māori concept of *whakapapa* conveys layered kinship across time, space, and species (Roberts, 2004). In such worldviews, ethics and ontology are inseparable: to exist is to be in relation. Recognition of ontological relationality reframes identity from autonomy to mutuality, inviting a deeper sense of interbeing and responsibility.

b) A Plurality of Ways of Knowing

Integral epistemology seeks to dissolve the binary between subjective and objective knowledge by recognizing diverse ways of knowing and becoming. Ferrer's participatory turn (2002) and Santos's "epistemologies of the South" (2014) challenge Western epistemic monocultures, advocating instead for transrational, embodied, and spiritual knowledges rooted in lived realities. This resonates with the work of Varela and Thompson on enactive cognition, where knowing arises from embodied interaction with the world (1991). Alan Rayner's concept of "inclusionality" redefines organisms not as bounded entities but as dynamic patterns of reciprocal flow (2011). Such thinking demands not only cognitive integration but also humility—a capacity to hold multiple truths without collapsing into relativism. Nora Bateson's "Warm Data" approach illustrates this by emphasizing contextuality, coherence, and qualitative complexity in perception (2021). Epistemology becomes not merely a method but a moral orientation toward life.

c) Ethics Emerges from Relational Ontology

This is not ethics as abstract rule but as lived responsiveness to context, community, and planet. Ubuntu *("I am because we are")* exemplifies an ethic of mutual recognition; *Buen Vivir* frames wellbeing as harmonious integration with Pachamama; Confucian role ethics emphasizes responsibility embedded in relational roles (Tu, 2004). These traditions contrast with Enlightenment ethics that prioritize autonomy and universality. Participatory ethics holds space for dialogue, situated judgment, and evolving reciprocity. It invites not only ecological responsibility but also healing—of interpersonal wounds, historical injustice, and intergenerational trauma. Contemporary applications include climate assemblies, restorative justice circles, and regenerative economics. These practices model ethics as a living, collective practice grounded in presence and care.

d) Narrative is not Peripheral - it is Ontological

Stories do not merely reflect reality; they co-create it. Language shapes perception (Sapir-Whorf hypothesis 1929), and thus reclaiming verb-rich, relational grammars—as Kimmerer and Four Arrows suggest—can alter our ontological frame. Pluralism here is not moral relativism but cosmological humility: the recognition that no single worldview holds the whole. Mythopoetic traditions from diverse cultures—such as the Dreamtime stories of Aboriginal Australia or the Kogi people's cosmologies—express truths carried in metaphor, ritual, and place. A pluralistic narrative ecology cultivates resilience, imagination, and intergenerational continuity. Cultural healing and planetary regeneration require the renewal of such narrative sources, especially those repressed by colonization and modernity. Media, education, and art are thus vital arenas for cultivating cosmological diversity and intercultural empathy.

e) The Unitive Worldview is Developmental

This perspective builds on a long lineage of developmental theorists who have mapped the evolution of human meaning-making across the lifespan. Abraham Maslow's late-career reflections on "self-transcendence" expanded his well-known hierarchy of needs to encompass experiences of unity, wholeness, and sacredness—qualities closely aligned with the Unitive paradigm (Maslow, 1971). Similarly, Richard Barrett's model of the Seven Levels of Consciousness offers a framework for understanding how individuals and collectives progress from survival and security to service and systemic contribution, reflecting a deepening alignment with shared values and planetary wellbeing (Barrett, 2016). In this frame, development is not linear but spiral-like—integrating earlier needs while expanding into new domains of relational and existential maturity. As Ken Wilber and Robert Kegan suggest, later stages of adult development involve the capacity to hold paradox, navigate ambiguity, and act from a sense of interconnected purpose (Wilber, 2000; Kegan, 1994). Crucially, these stages are not merely cognitive. They involve shifts in identity, perception, embodiment, and relational capacity. Yet access to these higher stages is not guaranteed. Trauma, social injustice, and structural inequality often inhibit the emergence of developmental

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coherence. Healing practices—ranging from somatic integration to collective rituals—are therefore essential to cultivate the conditions for Unitive awareness. This has led many scholars to call for "trauma-informed development" that integrates psychological healing with cultural transformation (Mate, 2022). Ultimately, developmental consciousness invites us to see the Unitive Worldview *not as an abstract ideal but as a living potential.* It is already being expressed in those who can weave across perspectives, act from compassion, and design from systems awareness. Scaling this potential requires not only inner work, but outer structures that support coherence—from education and parenting to policy and economics. The future of flourishing thus depends not only on what we build, but on who we become. Through its integrative approach to understanding and enhancing wellbeing at all scales, the Eco-Systemic Flourishing (ESF) framework (Ellyatt, 2025) presents a recent example of such new thinking, drawing upon developmental psychology, ecological systems theory, cultural anthropology, and regenerative economics to articulate a multi-dimensional view of flourishing. Rather than treating wellbeing as an individual attribute or economic outcome, ESF frames it as the result of dynamic interactions between people, cultures, and ecosystems.

At its heart, a Unitive Narrative tells the story of our shared becoming: that we are not isolated beings navigating a dead universe, but expressions of an evolving cosmos grounded in meaning, presence, and mutual care. Rather than ask, "What can I control or accumulate?", the Unitive lens asks, "*What am I part of, and how can I participate more consciously and compassionately*?"

Key Features of a Unitive Worldview:

- *Relational* rather than reductionist
- *Developmental* rather than fixed
- *Participatory* rather than extractive
- *Multicultural and Pluriversal* rather than monocultural
- *Living Systems-Oriented* rather than mechanistic
- *Ethically Generative* rather than rule-bound

Table 3: Key Features of a Unitive Worldview, Galileo Worldviews Study White Paper, 2025

Theme	Key Insight	Implication for Practice
Worldview Evolution	Humanity is transitioning from dualistic and fragmented paradigms to a relational, participatory worldview.	Support worldview literacy in education, leadership, and communication strategies.
Unitive Worldview	The Unitive Worldview integrates science, spirituality, Indigenous wisdom, and systems thinking.	Encourage cross-disciplinary dialogue and integrative frameworks in policy and learning.
Consciousness and Embodiment	Healing and flourishing require embodied, trauma-informed, and culturally coherent approaches.	Promote somatic, relational, and community-based mental health and wellbeing practices.
Wellbeing Measurement	There is global momentum to redefine progress through holistic and culturally relevant wellbeing metrics.	Adopt inclusive, developmental, and values-based frameworks such as Eco-Systemic Flourishing.
Future Generations	Intergenerational justice is gaining legal and moral traction in governance and global policy.	Institutionalize foresight tools and long-term wellbeing mandates at national and global levels.
Language and Perception	Language shapes reality: relational, verb-based, and indigenous grammars promote holistic worldviews.	Shift narratives in education, media, and governance to foster systems awareness and empathy.
Mathematics and Meaning	Emerging mathematical models (e.g. process geometry, transfigural logic) reflect the relational nature of life.	Integrate living systems mathematics into science education and design methodologies.
Trauma and Collective Healing	Healing personal and collective trauma is foundational for societal transformation.	Invest in inner development, social coherence, and cultural regeneration initiatives.
Education and Universities	Learning ecosystems must support planetary consciousness and systemic resilience.	Transform universities into unitive hubs for transdisciplinary innovation and civic renewal.
Governance and Ethics	Regenerative governance integrates care, complexity, and moral imagination.	Develop ethical frameworks that honor relational responsibility, inclusion, and planetary health.

VI. Education

Education is not merely the transmission of knowledge, but the shaping of perception, identity, and relational capacity. It plays a foundational role in determining the worldviews individuals develop—what they see as real, valuable, and possible. As such,

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transforming education is essential to any meaningful transition. This requires not incremental reform but a paradigm shift: from transmission to transformation, from standardisation to individuation, and from separation to relationship. Education in the Unitive paradigm recognises that the learner is not a passive recipient of facts, but a living system embedded in other systems—ecological, cultural, emotional, and spiritual. Learning is seen as a relational process that cultivates wholeness rather than fragmentation. Drawing on integral theory (Wilber, 2000), transformative learning (Mezirow, 1991; O'Sullivan, 1999), and Indigenous pedagogies (Narvaez & Four Arrows, 2022), Unitive Education aims to develop the full spectrum of human capacities: cognitive, emotional, ethical, intuitive, and imaginal. At the centre of this model is the importance of early years development. Research from attachment theory, neuroscience, and trauma-informed practice confirms that the first years of life are foundational for shaping the neurobiological architecture of empathy, trust, and worldview orientation (Siegel, 2010). Investment in secure caregiving, imaginative play, and relational coherence in early childhood is thus not merely a social good but a cultural imperative. Maria Montessori, Rudolf Steiner, and Loris Malaguzzi each recognised this, emphasising the importance of beauty, rhythm, nature, and autonomy in the early learning environment.

In later childhood and adolescence, Unitive Education shifts toward cultivating inner capacities for discernment, ethical reasoning, and systems thinking. This can be supported through dialogical inquiry, contemplative practice, arts integration, and engagement with real-world complexity. Practices such as *philosophy for children*, *ecopedagogy*, *permaculture design*, and *restorative justice circles* help students develop the ability to see patterns, hold paradox, and act with compassion. These approaches have been shown to increase not only academic performance but also wellbeing, empathy, and civic participation (Gidley, 2013; Scharmer, 2023). Higher education and lifelong learning must also be reimagined. Universities, long considered the apex of knowledge generation, often reproduce disciplinary silos and epistemic hierarchies that are antithetical to integrative wisdom. A shift toward regenerative learning ecologies—such as those being pioneered by the *Learning Planet Institute* and *Ubiquity University*—involves dissolving these silos and supporting transdisciplinary, embodied, and dialogical forms of inquiry. It also means rethinking assessment: moving from performance metrics to portfolios of practice, developmental feedback, and holistic evaluation.

A Unitive approach to education is not value-neutral. It explicitly affirms life, connection, and flourishing as its orienting principles. It seeks to cultivate planetary citizens who are not only skilled and informed, but also wise, humble, and capable of regenerating the commons. In a time of planetary transition, education is perhaps the most strategic lever for cultural regeneration. The Unitive Worldview offers a renewed foundation of meaning—one that can reorient education toward its deepest purpose: the cultivation of wise, connected, and caring human beings in service of a living Earth.

VII. The Impact of Technology

Technology, as both artefact and system, is one of the most powerful forces shaping modern consciousness. It structures how we communicate, learn, work, relate, and even perceive time and space. Yet technology is not neutral. It reflects and amplifies the values, assumptions, and worldviews of its creators and users. As such, the dominant technological paradigm of the modern-industrial worldview—characterised by control, extraction, acceleration, and externalisation—has contributed significantly to the fragmentation of planetary systems and the alienation of human experience.

The Worldview invites a reorientation: from technology as tool of domination to technology as partner in planetary regeneration. This shift entails designing and deploying technological systems that reflect the principles of relationality, participation, interdependence, and care. It calls for a move from "smart" technologies driven by optimisation and surveillance to "wise" technologies grounded in coherence, ethics, and ecological integration. One key area of transformation lies in artificial intelligence (AI). The techno-optimist vision, exemplified by Mo Gawdat (2021), posits that if guided wisely, AI can enhance collective wellbeing, solve coordination problems, and unlock new levels of creativity and abundance. This vision is compelling but incomplete. Critics such as Nate Hagens (2022) remind us of the biophysical realities—energy limits, ecosystem thresholds, and the psychological impacts of automation—that challenge such aspirations. The Unitive frame does not reject AI but reframes its telos: what is this intelligence in service to, and whom does it serve?

From this perspective, *Regenerative AI* emerges as a vital concept. Rather than training AI models on data driven by consumerist logics or extractive histories, regenerative systems learn from living patterns—ecological cycles, cultural wisdoms, and relational ethics. They prioritise coherence over optimisation, mutuality over manipulation. Pioneering examples include AI tools for ecological restoration, planetary boundaries monitoring, polycrisis mapping, and community participatory planning.Yet such technologies must be embedded within governance systems that reflect Unitive values. This includes algorithmic transparency, democratic participation in design, digital

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rights frameworks, and ethics that evolve with community input. The model of polycentric governance (Ostrom, 1990) offers a compelling template: distributed, relational, and adaptive systems of collective decision-making that can be mirrored in digital architectures.

Education in digital ethics and digital consciousness must also evolve. Beyond teaching media literacy or coding skills, a Unitive pedagogy addresses the *ontology of technology*: how does the use of this tool shape my experience of time, of self, of the other, of the world? This reflective layer—rooted in contemplative practice, philosophy of technology, and relational epistemologies—is essential for developing "technological wisdom." Furthermore, Indigenous and ancestral perspectives offer profound insights into technology as relational process. In many such traditions, tools and materials are embedded in ceremony, reciprocity, and place-based knowing. Technology is not divorced from life but integrated into ethical and spiritual frameworks. This worldview challenges the Cartesian split between user and object, inviting a reintegration of the sacred into design processes.

Finally, emerging technologies such as biomimicry, distributed ledgers, quantum computing, and immersive environments hold enormous potential—but only if guided by wisdom. The question is not simply *what* can we build, but *who* are we becoming as we build it? The Unitive Worldview calls for a culture of tech stewardship: designers, engineers, ethicists, artists, and citizens co-creating systems that honour life, diversity, and planetary wholeness.In this light, technology becomes not a threat to humanity but a test of it. Will we use our powers to dominate or to heal? Will we design systems that extract or systems that regenerate? The answers depend on the worldview we inhabit.

VIII. The Role of the Arts

The arts have long served as a mirror and a compass—reflecting cultural values while also guiding societies toward new modes of perception, feeling, and meaning. Within a Unitive Worldview, the arts are not ancillary but essential. They operate as a form of aesthetic epistemology: a way of knowing that is embodied, intuitive, symbolic, and relational. In an age marked by fragmentation and abstraction, the arts offer the possibility of reweaving coherence—across inner and outer experience, across disciplines and cultures, across generations and species. At their core, artistic practices engage the integrative faculties of the human being. They draw upon imagination, empathy, rhythm, and metaphor—capacities that are central to developmental maturity and to navigating complexity. Where analytical thinking isolates, the arts reveal interconnection; where linear models falter, the arts offer nonlinear depth. They make visible the invisible structures of emotion, belonging, and worldview. In this sense, they are indispensable tools for worldview transformation.

The Unitive Worldview affirms the arts not simply as expressions of individual creativity, but as participatory acts of world-making. Drawing on Indigenous aesthetics, ecological design, and participatory theatre, art is understood as a relational process—an interaction between humans, materials, places, and stories. This perspective reframes art as a communal technology for remembering, healing, and imagining. Practices such as collective mural-making, land-based installations, and oral storytelling circles embody this ethos. They are not only symbolic but systemic interventions—recalibrating social fields and ecological awareness. Contemporary artists working within this frame—such as John D. Liu's ecological filmmaking (2009), the theatre of Joanna Macyand the Work That Reconnects (2009), or the mythopoetic storytelling of Bayo Akomolafe (2020)—demonstrate how art can serve as a regenerative force. Their work does not aim to beautify a broken system but to unearth deeper truths, evoke shared mourning, and catalyse new patterns of participation. These practices resonate with what Indigenous scholar Gregory Cajete describes as "art-as-ceremony"—a process of aligning human creativity with the cycles and intelligence of the Earth (Cajete, 1994).

Moreover, the arts are vital in cultivating what philosopher Maxine Greene called *wide-awakeness*—a state of aesthetic and moral alertness to the world's suffering and beauty (2022). This attentiveness fosters what Martha Nussbaum terms the "narrative imagination": the ability to enter other lives, perspectives, and contexts, thereby expanding ethical sensitivity and systemic empathy (1996). These are not soft skills but civic virtues essential for relational governance and ecological regeneration. In education, arts-based pedagogies support holistic development and deeper worldview integration. Programs that integrate music, movement, visual expression, and creative writing into learning environments consistently enhance emotional regulation, cooperative behaviour, and integrative thinking (Gidley, 2010; Eisner, 2002). In early years education especially, play and aesthetic exploration support the development of symbolic literacy, narrative agency, and embodied cognition—cornerstones of future capacity for meaning-making. Within institutional and civic spaces, the arts also play a transformative role. Participatory art projects can serve as diagnostics of cultural fragmentation and as incubators of new social imaginaries. Initiatives like the *UCL Culture Lab*, *Art. Earth*, and the *Global CoLab Network* show how cross-sectoral collaborations between artists, scientists, and communities can foster emergence, insight, and collective coherence. These are

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not decorative interventions—they are infrastructure for navigating change.

Finally, the arts engage the spiritual and archetypal layers of human experience. Ritual, symbol, myth, and sacred geometry have always mediated between the seen and the unseen. As the Unitive Worldview re-integrates spirituality with systems thinking, the arts become a bridge between rational insight and mystical knowing. In this role, they help recover what Thomas Berry called the "great conversation" between humans and the more-than-human world.

In a time of polycrisis, when linear solutions fail and cultural narratives collapse, the arts invite us into the nonlinear, the felt, the emergent. They help us mourn what is lost, celebrate what is sacred, and imagine what is possible. As such, they are not peripheral to systemic change—they are central. The flourishing of planetary life will depend not only on science and policy, but on our collective capacity to sense, shape, and story a different world into being.

IX. Narrative Infrastructure and Worldview Media

Narratives shape attention, structure values, and frame collective imagination. They determine not only what we see, but how we see. As such, the dominant narratives of an era function as hidden architectures of meaning, profoundly influencing behaviour, institutional design, and societal priorities. The current narrative ecosystem—shaped by economic rationalism, competitive individualism, and technological determinism—has reinforced reductionist worldviews. Mass media often prioritises spectacle over substance, fragmentation over synthesis, and clickbait over complexity. In contrast, a Unitive Narrative seeks to reweave stories of relationship, regeneration, and collective possibility. To achieve this, we must develop intentional *narrative infrastructures*—cultural ecologies that support coherence, resonance, and pluralistic wisdom.Conscious media initiatives such as *The Wellbeing Economy Alliance's Narratives Lab*, *The Presencing Institute*, and *The Unitive Narrative Group* exemplify emerging efforts to transform how stories are created, circulated, and embodied. These initiatives recognize that cultural transformation depends as much on narrative coherence as on policy or economics. Their work involves "seeding the noosphere" with life-affirming, system-literate, and spiritually resonant stories that can guide new forms of collective behaviour.

Equally important is the reclamation and integration of Indigenous and ancestral narrative traditions. Oral cosmologies, mythic time, ritual storytelling, and seasonal festivals are not peripheral cultural artefacts but sophisticated systems for embedding ecological awareness, intergenerational knowledge, and moral orientation. For example, the Māori concept of *whakataukī* (proverbs) carries encoded wisdom about social conduct and environmental stewardship, while Andean *cosmovisión* rituals integrate agricultural cycles with cosmic order. These narrative forms operate as "living knowledge systems" that hold deep relevance for navigating uncertainty and change. Media, in this expanded frame, becomes not only a technological domain but a sacred function: the means by which a society reflects, heals, and reimagines itself. Storytelling becomes a civic practice of worldview cultivation. This can be seen in regenerative media platforms, participatory documentary processes, and transmedia campaigns that involve audiences not just as consumers, but as co-creators of meaning.

Just as public health depends on sanitation infrastructure, so too does cultural health depend on narrative infrastructure. Without intentional cultivation, societies become vulnerable to disinformation, polarisation, and existential numbness. But when the stories we tell are life-affirming, context-sensitive, and emotionally intelligent, they can re-pattern collective identity and behaviour in profound ways.

A Unitive Worldview thus calls for a new generation of *narrative stewards*: artists, educators, media architects, and cultural facilitators who can tend the symbolic commons. Their work is to support a shared transition from fragmentation to coherence—through stories that honour the depth, dignity, and interdependence of all life.

X. Governance and Institutional Shifts

A Unitive ethic calls for polycentric governance, intergenerational responsibility, and post-GDP wellbeing metrics (Jonas, 1984; Raworth, 2017; Stiglitz et al., 2018). Legal frameworks such as the Wellbeing of Future Generations Act (2015) in Wales and the growing global movement for rights of nature legislation reflect this evolution. Such frameworks prioritize long-term ecological health and social cohesion over short-term economic growth, embedding future-oriented values in law and policy.

Central to this shift is a reimagining of political legitimacy and decision-making authority. Polycentric governance systems distribute power across multiple levels—local, regional, national, and global—enabling adaptive responses to complex, interlinked crises. This stands in contrast to hierarchical, top-down models that often fail to engage community wisdom or respond nimbly to change. Drawing on Elinor Ostrom's work on common-pool resources, governance under the Unitive Worldview recognizes the importance of local agency, collaborative institutions, and trust-based social contracts.

Institutions that aspire to embody a Unitive Worldview must look beyond surface-level reform and address the deeper architectures—legal, financial, and

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cognitive—that shape societal functioning. Dark Matter Labs, a systems innovation collective, describes these as the "dark matter" of society: the often-invisible frameworks of contracts, governance protocols, and digital infrastructure that configure our collective imagination and behaviour. Their work on civic trusts, legal design for commoning, and regenerative finance demonstrates how institutional DNA can be rewired to align with principles of polycentric governance, interdependence, and long-term care. By prototyping emergent civic architectures, they offer a live expression of unitive ethics translated into systems infrastructure (Dark Matter Labs, 2022).

Economically, the transition toward wellbeing-oriented governance necessitates integrating new metrics, such as the Genuine Progress Indicator, Doughnut Economics frameworks, and measures aligned with the Inner Development Goals. These tools support systems of accountability that reflect human flourishing, planetary boundaries, and intergenerational equity.

Other institutions—such as health systems, media organizations, and philanthropic foundations—can also be restructured to align with unitive principles. For example, participatory budgeting and citizens' assemblies offer democratic innovations that bring values of relationality, dialogue, and shared responsibility into political life. Similarly, impact investing and regenerative finance models shift capital allocation toward long-term cultural and ecological regeneration. Ultimately, the institutional embodiment of a Worldview requires more than reform; it requires a re-grounding in principles of interconnectedness, justice, and care. By redesigning the systems that shape our lives, we can better align them with the values and capacities needed to navigate the metacrisis and cultivate a flourishing future for all beings.

XI. Challenges and Future Directions

Critics worry that a Unitive Worldview risks epistemic relativism or spiritual idealism. Some argue that its emphasis on subjective knowing, cultural pluralism, and spiritual insight could erode the empirical rigor and universal applicability traditionally valued in science and policy. These concerns are not without merit, especially in contexts where misinformation, pseudoscience, or ideological extremism thrive. However, metatheoretical approaches show how diverse ontologies can coexist without collapsing into incoherence. Hedlund (2010) and Santos (2007) have both argued that an integrative pluralism—one that respects difference while cultivating coherence—is essential for navigating complex global challenges. Another critique comes from within activist and decolonial movements, where there is concern that the Unitive Worldview may be appropriated in ways that erase or dilute Indigenous voices (Tuck & Yang, 2012). If not grounded in reciprocal relationships and power-aware practices, integrative frameworks risk reproducing the very domination they seek to transcend. Future research and practice must therefore attend to questions of epistemic justice, historical trauma, and authentic partnership.

Institutionally, resistance may also stem from the inertia of entrenched systems. Bureaucracies, accreditation bodies, and political mechanisms are often ill-equipped to support the emergence of new worldviews. Realigning these structures requires leadership development, capacity building, and courageous experimentation. Organizations like the Wellbeing Economy Alliance, the Inner Development Goals, and the Earth Charter Initiative are modelling how such transformations can unfold.

Empirically, much work remains to be done. While conceptual models such as ESF and Integral Theory are promising, robust tools are needed to assess worldview evolution and its systemic impacts. This includes the development of metrics, longitudinal studies, and participatory evaluation methods. Educational interventions, in particular, require assessment tools that can track shifts in cognitive complexity, moral reasoning, and relational awareness over time. Finally, the digital infrastructure of society must be scrutinized. Algorithms, platform governance, and data ownership structures shape collective meaning-making at scale. Future research should examine how digital systems can support integrative dialogue, ecological awareness, and pluralistic solidarity—rather than fragmentation, outrage, and commodification.

For this transformation to take root, institutions must evolve—from education to governance, from digital platforms to financial systems. These changes will not be easy. They require courage, creativity, and collective commitment. But they are already beginning—in the experiments of regenerative communities, the visions of new legal frameworks, and the insights emerging from transdisciplinary dialogue. A Unitive Worldview does not offer final answers, but it offers a generative orientation: a way of seeing and being that is grounded in care, complexity, and the possibility of flourishing for all life. In a world increasingly defined by fragmentation, it may be the most essential compass we have.

XII. Conclusion

The Unitive Worldview represents not merely an intellectual synthesis or a philosophical alternative—it is a developmental imperative for humanity at a time of planetary transition. The interlinked crises of our era—ecological collapse, social fragmentation, technological disruption, and existential despair—are symptoms of a

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deeper epistemological failure: a fragmentation in how we perceive ourselves, each other, and the living world. As this paper has argued, addressing the metacrisis requires more than new technologies or policies. It requires a transformation in consciousness and culture, rooted in a relational, participatory, and life-affirming understanding of reality. By integrating insights from systems theory, developmental psychology, Indigenous wisdom, regenerative science, and spiritual cosmologies, the Unitive Worldview offers a coherent frame for navigating complexity without collapsing into either relativism or reductionism. It transcends outdated binaries—subjective/objective, science/spirituality, individual/collective—and instead cultivates coherence across domains: inner and outer, personal and political, human and ecological.

To fully activate this paradigm, our institutions must also transform. Education systems must cultivate whole human beings—not merely skilled workers but wise, empathic, and ecologically attuned citizens. Media must evolve from attention extraction to narrative integration. Technology must be reimagined not as an end in itself but as a tool in service of coherence, humility, and stewardship. Governance must move from hierarchical command to polycentric care, with future generations and non-human life represented in decision-making. The Unitive Worldview does not negate science, reason, or critical thinking. It expands their scope and recontextualises their purpose. It does not idealise the past nor impose a utopian blueprint. Rather, it offers an evolving compass—an orientation grounded in the ancient and the emergent, the intuitive and the empirical, the personal and the planetary. It calls us to re-member what has been dismembered, to re-weave the torn fabric of life.

In the face of escalating global challenges, the need for a unitive and sustainable worldview has never been more urgent. Such a perspective is grounded in five core principles that foster ethical, systemic, and regenerative engagement with the world.

1) Right Relationship: emphasizes reciprocal and ethical interactions between humans and nature, drawing from ecological ethics and Indigenous wisdom to promote sustainability and planetary stewardship, including the promotion of dignity and meaningfulness for both human and non-human lives (Kimmerer, 2013; Plumwood, 2002, Godfrey-Smith, 2024).

2) Systems Thinking: recognizes the deep interconnectivity of all systems, highlighting the importance of feedback loops and emergent complexity in shaping social and ecological resilience (Meadows, 2008; Capra & Luisi, 2014).

3) Integral Epistemology: integrates empirical science, wisdom traditions, and direct experience, enabling a multidimensional and transdisciplinary approach to knowledge (Wilber, 2006; Ferrer, 2002).

4) Participatory Decision-Making: which fosters decentralized, adaptive, and community-driven governance models that enhance collective agency and legitimacy (Ostrom, 1990; Fung, 2004).

5) Intergenerational Ethics: underscores the responsibility to prioritize long-term planetary well-being, ensuring that decisions made today safeguard the interests of future generations (Jonas, 1984; Raworth, 2017).

Together, these principles provide a robust and actionable framework for addressing 21st-century challenges, fostering a regenerative and inclusive future that aligns with both human flourishing and ecological integrity.Crucially, this transformation cannot be imposed. It must be grown—through dialogue, education, healing, and practice. It must arise within communities and cultures, through trust, participation, and story. It must include the wisdom of the many—Indigenous elders, system scientists, spiritual leaders, regenerative practitioners, and young visionaries. It must be both a rising from below and a remembering from within. In a world increasingly defined by division and disruption, the Unitive Worldview invites us to anchor in connection, coherence, and care. It is a vision not of escape, but of engagement. Not of heroic salvation, but of mutual regeneration. It is a worldview whose time has come—not because it offers easy answers, but because it enables us to ask deeper questions, together.

If we are to survive and flourish, not only as individuals but as a species among species, we must learn to think, feel, and act in ways that reflect the interbeing of all life. The Unitive Worldview, and the frameworks it inspires, offer us this possibility—not as prophecy, but as practice. And perhaps, as Einstein urged, this new way of thinking may indeed be the condition for our collective survival.

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On the Origin of Cockroaches in the Maltese Islands

By Arnold Sciberras

Introduction- The Maltese Islands, located in the central Mediterranean, have a rich biodiversity influenced by their strategic position as a crossroads between Europe, North Africa, and the Middle East. Among the many species that have adapted to the island environment, cockroaches (Order: Blattodea) hold a unique position. Their presence reflects both natural dispersal and human activities over millennia. This essay explores the origins, distribution, and documented records of cockroach species in Malta, shedding light on their historical and ecological significance.This work also includes two new species for the islands..

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On the Origin of Cockroaches in the Maltese Islands

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I. Introduction

The Maltese Islands, located in the central Mediterranean, have a rich biodiversity influenced by their strategic position as a crossroads between Europe, North Africa, and the Middle East. Among the many species that have adapted to the island environment, cockroaches (Order: Blattodea) hold a unique position. Their presence reflects both natural dispersal and human activities over millennia. This essay explores the origins, distribution, and documented records of cockroach species in Malta, shedding light on their historical and ecological significance.This work also includes two new species for the islands.

II. Early Origins and Natural Dispersal

Cockroaches are ancient insects, with fossil records dating back over 300 million years to the Carboniferous period. Their resilience and adaptability have enabled them to thrive in diverse environments. Over 5,500 species are known worldwide. The oldest exposed rock layer of Malta is the Lower Coralline Limestone Formation (Maltese: Żonqor), which is of Chattian age (~28–23 million years old) with a maximum thickness of 162 m. Tectonic activity was the prime assist and the islands were initially devoid of terrestrial life. As the islands stabilized, they became colonized by various species, including cockroaches, either through natural dispersal mechanisms such as rafting on vegetation or by wind-assisted transport from nearby land masses.

III. Human-Mediated Introduction

The more significant factor in the introduction of cockroaches to Malta has been human activity. The islands have been inhabited since the Neolithic period (circa 5200 BCE), and with the arrival of humans came the unintentional transport of various flora and fauna, and cockroaches were no exception. Trading activities, especially during the Phoenician, Roman, and later Arab and European periods, facilitated the spread of numerous cockroach species.

IV. The Origins Of The Maltese Name

According to Caruana, the word *wirdien* is derived from *werden* (which itself comes from *radari*), suggesting that the insect earned its name from the hoarse, continuous sound it makes — a sound likened to the turning of a wheel in motion as it flies. Caruana further explains that *werden* refers to the sound of "the wheel that spins cotton."

Barbera supports this theory, adding that the term refers to "the iron spindle used by wool spinners," and that by analogy with its movement, the Maltese adopted the word to describe the cockroach.

Serracino Inglott, however, offers a different perspective. He challenges the *werden* theory, arguing that the linguistic evolution from *werden* should have resulted in the word *werdien* rather than *wirdien*. He instead references Dozy, who proposes that the word might stem from flower-related terms, particularly from "flour delicates which resemble the texture of floss silk or flower stamens, whose perfumes are carried away by the breeze." The petals — or *loqom*, as Cremona refers to them — are said to resemble the cockroach's wings. In other words, these much-maligned insects might, surprisingly, be etymologically linked to the beauty of roses.

The etymology provided by Caruana and Barbera is rooted in the sound these insects make in flight. Yet, this raises further questions, as only one of the three main species of large cockroach found in Malta (P. americana) is a frequent flier. One species (B. orientalis) cannot fly at all, having lost its wings, and the other species rarely takes flight.

It is plausible that the term *wirdien* was initially used to refer to beetles commonly found on flowers and was later extended to other insects, such as the cockroach, as it is used today. This linguistic shift is not unique to Maltese. In Italian, for example, the word *scarafaggio* (cockroach) comes from the Latin *scarabeus*, referring to a type of beetle (Family Scarabaeidae), which, like many beetles, can often be found on flowers.

Dessoulavy (1938) also defines *wirdiena* as 'beetle', though this may have stemmed from imprecise scientific knowledge at the time. Regardless of its exact origin, the word *wirdien* is undoubtedly ancient — appearing as early as the dictionary of the Knight Thezan, as noted by Cassola.

V. Possible First Records

Although the exact origins of these introduced species cannot be definitively traced, various hearsay accounts provide clues about when they were first recognized in Malta. The presence of Maltese names with Arabic linguistic roots suggests that these species

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may have been known as early as the Arab colonization, whether as introduced or native species. However, concrete historical records from that period are lacking. Additionally, numerous anecdotes associate their presence with the era of the Knights of St. John, further emphasizing the role of oral tradition in shaping local knowledge. While hearsay cannot replace documented evidence, it offers valuable insights into the historical awareness and cultural significance of these species. The author has compiled these accounts alongside available historical data to provide a broader perspective.

One piece of hearsay collected by the author recounts that, during the time of the knights, women of the streets faced particular issues with these critters inhabiting the corners of their workplaces. To deal with the nuisance, they would call upon their protectors—what we would refer to today as pimps—to eradicate the unwanted pests. It is said that a type of benzene was commonly used to ward off these organisms as much as possible.

This story has led to speculation about the origins of the Maltese word for cockroach—wirdien or werden. Some believe it derives from the verb werwer, meaning "to scare," as these pests were notorious for startling women who worked the streets at night. This linguistic connection suggests that the name may have originated from the fear or unease these creatures caused. Given that language often evolves through cultural experiences and oral traditions, it is possible that the term became widely adopted due to such encounters. However, without documented linguistic records, this remains a compelling yet unverified theory.

During his pest management activities, the author discovered remnants of cockroach parts within historic books stored in an old book repository that date back to the 1400. Thanks to the expertise of book conservator Simon Sultana, additional fragments—such as legs and thoraxes—were also identified. These findings allowed the author to determine which cockroach species had once inhabited the repository (B.orientalis) and possibly became trapped within the archival books over time. (carbon dating is being looked at.)

In 1862, renowned naturalist Alfred Russel Wallace made a stop in Malta while transporting two live birds of paradise to Europe. During his stay, he obtained a significant number of cockroaches from a local bakehouse (Possibly *P. Americana*), using them as a crucial food source to sustain the birds. This historical account highlights the presence and abundance of cockroaches in Malta at the time, reinforcing their long-standing association with human settlements. Wallace's observations provide an early documented link between these insects and Malta's urban environments.

VI. Timeline of the Cockroach Recordedspecies in Maltese Islands

Several cockroach species have been recorded in Malta, with their presence documented by entomologists over the past century. Drawing from the work of Bohn and Sciberras (2021) and Sciberras & Sciberras (2024), the following is a comprehensive list of each recorded species (by date not by family or genus) and their introduction or discovery in the Maltese Islands.

The first cockroaches recorded in Malta were documented by Professor John Borg in his 1939 work. These included the American cockroach *(Periplaneta americana* Linnaeus, 1758*)*, the Brown-banded cockroach *(Supella longipalpa* Fabricius, 1798), and the Egyptian cockroach *(Polyphaga aegyptiaca* Linnaeus, 1758). Of these, the Egyptian cockroach is considered native to the region, thriving in dry, arid environments typical of the Mediterranean climate. It is also native to arid and semi-arid regions of North Africa and the Middle East, particularly the Sahara and Arabian deserts, where it is well-adapted to extreme temperatures and low humidity. It is often found in rocky areas, under stones, and in semi-natural habitats, rather than inside human dwellings, distinguishing it from the other two species. In contrast, the American cockroach and the brown-banded cockroach are both non-native species that arrived in Malta through human activity. The American cockroach, one of the largest and most widespread urban cockroaches. Once established, it thrives in warm, humid environments, particularly in sewers, basements, and industrial kitchens. *P. americana*, commonly known as the American cockroach, is a large, synanthropic cockroach species of significant medical and economic concern. Despite its common name, *P. americana* is not indigenous to the Americas. Phylogeographic and historical evidence indicates that its native range is in tropical West Africa. The species is believed to have been introduced to the New World in the early 17th century, primarily via transatlantic shipping routes during the period of intensified global maritime trade. From its initial introduction in port cities, P. americana rapidly expanded its range, aided by human activity and its high adaptability to anthropogenic environments. Currently, P. americana exhibits a cosmopolitan distribution, especially in tropical and subtropical regions, although it also persists in temperate climates through association with heated human dwellings. It is commonly found in sewer systems, basements, commercial kitchens, food storage facilities, and other urban infrastructures where warmth, moisture, and food are abundant. The species has established stable populations in nearly every continent except Antarctica. Its success as an invasive species is attributed to its broad ecological tolerance, high reproductive potential, and efficient dispersal

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through human-mediated transport, particularly in globalized trade and shipping. In 2019 a white eyed population was found in a Cemetery in Paola village. In 2020 three domestic breeds of this species were documented to have been developed locally for scientificresearch and for the entomological breeding enthusiasts. In 2024 a very dark population was discovered in the island of Gozo suggesting crossbreeding with these domesticated possibly escaped breeds.

The Brown-banded cockroach, a much smaller species, has a different ecological preference. It is often found in indoor environments, especially in homes, hotels, and offices, where it hides in furniture, behind wallpaper, and in warm electrical appliances. This species likely spread to Malta through imported goods, luggage, or second-hand furniture, as it is well adapted to surviving in human-made environments. It said that this species was introduced in the first world war. This synanthropic cockroach has achieved a global distribution in human environments. Unlike many other peridomestic cockroaches, S. longipalpa prefers drier and warmer areas within buildings, often occupying higher locations such as ceilings, cabinets, electrical appliances, and furniture. The species is believed to be native to tropical Africa, although its precise origin is less well-documented than that of Periplaneta americana. Its spread to other regions has been facilitated entirely by anthropogenic means, especially through commerce and human migration. Today, S. longipalpa is found on every continent except Antarctica, with particularly established populations in urban and indoor environments.

By 1954, additional cockroach species had been recorded Anthony Valletta, including the Oriental cockroach (*Blatta orientalis* Linnaeus, 1758) and the native Field cockroach (*Loboptera decipiens* Germar, 1817).

The Oriental cockroach is a non-native species that likely arrived in Malta through maritime trade, much like the American cockroach before it. It thrives in cool, damp environments, making it a common inhabitant of sewers, drains, basements, and shaded outdoor areas. Unlike the American cockroach, which prefers warmer and more humid conditions, the Oriental cockroach is more tolerant of lower temperatures and can often be found outdoors in leaf litter, under stones, or near water sources. Its dark, shiny appearance and sluggish movement make it distinct from other urban cockroach species. Although it was rare locally in the past, in the last 15 years it made a steady increase.

The Field cockroach, on the other hand, is a non-pest species that is well adapted to Malta's natural landscapes. Unlike the invasive urban cockroaches, the latter are outdoor dwellers, commonly found in grasslands, rocky terrain, and shrublands. They are lighter in color and more agile, resembling small grasshoppers in their behavior. These cockroaches play a role in the ecosystem by feeding on decaying plant material and being a food source for insectivorous animals. In the Maltese islands two forms are present and in some minor islets, it is suspected that an undescribed species is present (Sciberras, A. Unpublished work).

By the late 1960s, the German cockroach (*Blattella germanica* Linnaeus, 1767) is believed to have arrived in Malta, marking a shift in the local perception of cockroach infestations. Many locals began referring to this species simply as "Kokroc", while reserving the Maltese term "Wirdiena" for the larger cockroach species, such as the American cockroach (*Periplaneta americana*). This suggests that by this period, the German cockroach had become the dominant household pest, overtaking previous species in recognition. (Sciberras, A. Unpublished work).

Between the battle of local dominance between B. germanica and S. longipalpa, Green Banana cockroaches (Panchlora sp Burmeister, 1838) were documented. These species are primarily native to tropical and subtropical regions of Central and South America. In Malta, occurrences of Panchlora species have been sporadically documented, primarily linked to imported goods. The first recorded instance dates back to 1975, when a specimen was found, as reported by Ebejer in 2020. Subsequently, in 2015, two specimens were discovered in a supermarket in Paola by the author. These findings were associated with freshly imported bananas, suggesting that the cockroaches were inadvertently introduced via fruit shipments. Notably, there have been no reports of Panchlora species on banana plants cultivated within Malta, indicating that these cockroaches have not established local populations and are not considered part of the native fauna. Globally, Panchlora species are often found in warm, humid environments and are typically associated with vegetation. They are nocturnal and are attracted to lights, which can lead them into human dwellings, although they are generally not considered pests. Their presence in non-native regions is frequently linked to the importation of goods from their native habitats, as evidenced by the cases in Malta. Despite these incidental introductions, there is no substantial evidence to suggest that Panchlora species have established sustainable populations outside their native range.

Interestingly, the Brown-banded cockroach may have been more common than the German cockroach during the early years locally, but at some point—perhaps by the 1990s—the German cockroach became the more widespread and recognized urban pest. Stephen Schembri later recorded the German cockroach in 1980, though without citing sources, further reinforcing its established presence by this time. Today, these two species have developed particular

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ecological boundaries within the Maltese Islands. The German cockroach is the most widespread and is found primarily in kitchens, restaurants, and food storage areas, thriving in warm, humid environments. It reproduces rapidly, with shorter breeding cycles and large population booms, making it a notorious pest but relatively easier to eradicate with insecticides and baiting techniques. In misscontrast, the brown-banded cockroach, while less common, has a unique advantage—when it is present in an area, it tends to completely outcompete the German cockroach. It breeds more slowly but is more persistent, favoring drier, warmer environments, such as cupboards, furniture, and even bedrooms, where it can avoid direct competition with the German cockroach. Once established, it is much harder to remove, as it disperses its eggs in hidden locations, making extermination efforts more challenging.

In the same publication, Stephen Schembri recorded the Sicilian wood cockroach (*Ectobius kraussianus* Ramme 1923) from a single location, the Buskett area. However, modern research suggests that the species he documented may have actually been the Maltese cockroach (*Ectobius melitensis* Bohn & Sciberras, 2021), a species now recognized as endemic to Malta. Unfortunately, due to the unavailability of Schembri's original specimens, there is no definitive evidence to confirm whether his identification was correct or whether he had mistakenly classified the Maltese as the Sicilian wood cockroach. Given the geographical distribution of E. kraussianus—which is not typically associated with the Maltese Islands—this misidentification seems plausible.

The Southern Madagascar hissing cockroach (Gromphadorhina sp. Brunner von Wattenwyl, 1865) was first recorded in Malta in 1999, initially found in homes and garages of individuals who had previously kept them as pets. These large, flightless cockroaches, originally from Madagascar, are popular in the pet trade due to their size, docile nature, and ability to produce a distinctive hissing sound. At first, these cockroaches were only found in human dwellings, suggesting accidental escapes or deliberate releases. However, since 2016, there have been indications that they may be able to move between houses and even survive in the wild, raising concerns about their potential to establish a population in Malta's environment. The authors of the 2021 study documenting their presence did not attempt to determine the exact species within the Gromphadorhina genus. This is due to the extreme variability in size, coloration, and markings seen in captive-bred populations, a challenge previously highlighted by Van Herrewege (1973) in his revision of the Gromphadorhini tribe. Because of this variability, determining the species of these introduced individuals is difficult without detailed genetic or morphological analysis. Although hissing cockroaches are not considered pests, their ability to survive outside captivity in Malta raises interesting questions about their long-term adaptability and potential ecological impact, especially if they become part of the local ecosystem.

A single male and female specimen of Amber wood cockroach (*Ectobius vittiventris* Costa,1847) were collected in 2001 from a small area with garrigue-like vegetation near a heavily frequented industrial port in an area known as Kordin were collected by the author. Despite repeated searches in and around the locality, no further specimens were found. This suggests that the species was likely introduced through human activity but is not established in Malta. This species is native to southern Europe, particularly prevalent in Mediterranean regions such as southern Spain, France, Italy, and the Balkans. Its range extends into western Asia, including countries like Turkey, Georgia, Azerbaijan, and southwestern Russia. In recent decades it has notably expanded its distribution northward. Since around 1999, it has been observed in northern Switzerland, with subsequent records in Germany (first noted in 2002), Austria, Slovakia, Hungary, the Czech Republic, and Great Britain. This expansion is attributed to factors such as climate change and human-mediated dispersal. Ecologically, this species inhabits outdoor environments, favoring low bushes, gardens, and areas with abundant leaf litter. It primarily feeds on decomposing plant material and is considered harmless to humans, as it does not infest homes or act as a storage pest. Occasionally, adults may enter human dwellings, especially when attracted to artificial lights, but they typically perish within a few days due to unsuitable indoor conditions. The species is capable of flight, which facilitates its dispersal and occasional entry into homes.

Jeffrey's Fungus Rock cockroach (*Heterogamisca jeffreyana* Bohn & Sciberras 2021) is a species endemic to Malta, discovered by author in 2006 and named in honor of his botanist brother, Jeffrey Sciberras. This species was first identified on Fungus Rock (Ġebla tal-Ġeneral) in Dwejra, where it was found inhabiting the nests of aquatic marine birds. It is believed to feed on bird feces, contributing to nest hygiene. The Heterogamisca genus is primarily found in Africa, but little else is known about this specific species due to its elusive nature. Most likely, the species has a wingless female as is true for the other members of this genus. Till now no females were found and is yet to be described.

The Australian cockroach (*Fortiblatta australasiae* Fabricius, 1775) was first recorded in Malta in 2012, with initial specimens collected from Wied Dalam (Birżebbuġa) and later that same year from the village of Għaxaq. In 2015 and 2016, remains of two female specimens were found in Marsaxlokk and Marsaskala, respectively. In 2024 and 2025, several small populations were detected across southern parts

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of the island, yielding a total of 103 specimens. This species is a widespread peridomestic species native to tropical Asia and possibly Australia, but now found globally in warm climates, especially in greenhouses, ports, and urban environments. Its spread is largely attributed to human activity and global trade.

Dubia roach (*Blaptica dubia* Serville, 1838) is a species native to South America, particularly found in Brazil, Argentina, and Uruguay. The first recorded presence of *B. dubia* in Malta dates back to 2012. Specimens were discovered in various locations associated with the pet trade from the author's company technicians where they were bred in colonies within houses, garages, and gardens. However, their ability to overwinter appears limited to indoor environments. In their native habitat*, B. dubia* thrives in warm, humid environments. Optimal conditions for their growth and reproduction include temperatures between 25–30°C and relative humidity above 60%. This species exhibits sexual dimorphism; adult males possess fully developed wings but are not strong fliers, while females have only rudimentary wing stubs. They are generally slow-moving and unable to climb smooth surfaces, making them less invasive compared to other cockroach species. These traits, along with their high protein content and ease of breeding, have made them popular as feeder insects in the pet trade. In Malta, their presence is primarily associated with human habitation, and there is no significant evidence to suggest they pose a threat to indigenous species or natural ecosystems.

The Turkestan cockroach(*Periplaneta lateralis* Walker, 1868) was first recorded in the Maltese Islands in 2013, mainly associated with the pet trade. However, stable populations have since been found in caves and cave-like structures outside human settlements. This suggests that the species has established itself beyond captive environments. This species is native to Central Asia, particularly Turkmenistan, Uzbekistan, and Afghanistan. Due to the pet trade (as feeder insects for reptiles and arachnids) and accidental transport, it has spread toMiddle East (Widespread in Iran, Saudi Arabia, and Israel). In Europe there are Introduced populations in Spain, France, Italy, and Germany. In North America it is well established in the southern U. S., particularly Arizona, Texas, California, and New Mexico. In Asia there are reports from India and China. Also known from some parts of Australia and South America, likely introduced through trade. It prefers warm, arid conditions and is often found in urban areas, around buildings, and in dry natural habitats like caves and rocky shelters.

The Smoky brown Cockroach (*Fortiblatta fuliginosa* Serville, 1839) was first recorded in the Maltese Islands in 2014. Since then, at least one or two specimens have been documented annually, occasionally in association with the American Cockroach, indicating a potential for cohabitation in urban environments. Native to Southeast Asia, P. fuliginosa has spread to various parts of the world through human activity. It is now established in the southern United States (especially the southeastern states), parts of Central and South America, the Caribbean, Africa, Australia, and parts of East Asia. It thrives in warm, humid environments and is commonly found in outdoor settings such as gardens, woodpiles, and attics, but may also enter buildings.

The Lobster Cockroach (*Nauphoeta cinerea* Olivier, 1789) was first recorded in the Maltese Islands in 2014, with the initial specimen discovered in a garage in Żabbar. The species is believed to have become established following accidental release from the pet trade, where it is frequently used as a feeder insect for reptiles and amphibians. By 2016, it had spread across much of the southern region of Malta, suggesting successful establishment and local proliferation, particularly in urban and semi-urban environments with suitable shelter and warmth. This species is native to tropical Africa but has achieved a nearly cosmopolitan distribution through human activity. It is widely kept and traded as a feeder species and has been introduced to indoor environments in Europe, North and South America, Asia, and Australia. In temperate regions, it rarely survives outdoors but can persist in heated buildings such as pet shops, zoos, and greenhouses.

The Unadorned Cockroach (*Symploce pallens* Stephens, 1835) was first documented in Malta in 2016. Initial findings were made indoors in Gudja and Għaxaq, and later in Paola, where individuals were observed attracted to artificial light sources at night. Between 2016 and 2023, the species was repeatedly encountered during pest control activities, with over 100 specimens recorded. However, no individuals have been found since 2023, suggesting a possible population decline or local disappearance.Native to Southeast Asia*, S. pallens* has been introduced to various parts of the world, particularly in subtropical and tropical regions. It is commonly associated with human habitations and tends to inhabit warm, sheltered indoor environments. Established populations have been recorded in parts of southern Europe, the Middle East, and the Americas, typically in greenhouses, warehouses, and residential buildings.

The Pallid cockroach (*Phoetalia pallida* Brunner von Wattenwyl, 1865), was first recorded in Malta in 2017, with the initial specimen discovered at Naxxar village The species is presumed to have been introduced via imported ornamental plants or gardening materials. Following its introduction, *P. pallida* rapidly established a local population, becoming common in the residential area of Ta' San Pawl tat-Tarġa, where it has been observed inhabiting plant pots and garden soil. To date, the species has been recorded in 63 households within Naxxar, although no sightings have

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yet been reported outside the village. *P. pallida* is native to Central and South America but has become a pantropical species through human-mediated dispersal. It is now found in various parts of Africa, southern Asia, Australia, and several Mediterranean countries, typically associated with greenhouses, nurseries, and urban gardens.

The Surinam cockroach, (*Pycnoscelus surinamensis* Linnaeus, 1758), was first recorded in Malta in 2017. It was presumably introduced through the importation of potted plants or gardening materials. The species was initially discovered in Birkirkara, particularly in the Ta' Paris area, where it quickly established itself in garden soils and plant pots. Since then, it has been recorded in at least 100 households in that locality. Additional occurrences have been documented in Burmarrad and in a plant nursery in Qormi, suggesting a slow but steady spread across horticultural environments. The Surinam cockroach is native to Southeast Asia but has become pantropical through human-assisted dispersal. Today, it is widely distributed in tropical and subtropical regions across Africa, the Americas, southern Europe, Asia, and Australia. It is commonly associated with greenhouses, nurseries, and gardens. Notably, the species reproduces through parthenogenesis, meaning all individuals are female and capable of producing offspring without mating—an adaptation that enhances its ability to colonize new areas rapidly.

The Indian borrowing cockroach (*Pycnoscelus indicus* Fabricius, 1775), was first recorded in Malta in 2017. However, debate regarding whether the specimens were actually *P. surinamensis* persisted until 2022. The species was presumably introduced through the importation of potted plants or gardening materials. It was initially discovered in Naxxar and, to date, remains confined to this locality. The Indian Burrowing Cockroach and the Surinam Cockroach are two closely related species that are often confused due to their similar morphology. However, they can be distinguished by several key traits. *P. indicus* typically has a broader and more robust body, with slightly darker coloration, and males possess fully developed wings that extend beyond the abdomen, unlike the often brachypterous (short-winged) males of *P. surinamensis*. Additionally, *P. indicus* tends to show more pronounced lateral expansions on the pronotum and differences in genitalia structure, which are important in taxonomic identification. In terms of distribution, *P. surinamensis*, also known as the greenhouse cockroach, has a nearly cosmopolitan range and is commonly found in tropical and subtropical regions worldwide, often in greenhouses, plant nurseries, and compost piles. It reproduces parthenogenetically, which aids in its rapid spread. *P. indicus*, by contrast, is native to South and Southeast Asia and has a more limited global distribution, although it has been reported in several introduced locations, often associated with the horticultural trade. Its spread is typically slower and more localized compared to the highly invasive *P. surinamensis*.

Two specimens of the Giant lobster roach (*Henschoutedenia flexivitta* Walker, 1868) were found first in 2018 in Qormi village in a plant nursery and a female was found in 2024 in the same location. The occurrence is almost certainly the result of accidental introduction via imported ornamental plants or associated horticultural materials. There is no current evidence suggesting that this species has established a breeding population in Malta. This species is native to sub-Saharan Africa and parts of Southeast Asia. It has been recorded in countries such as the Democratic Republic of Congo, Nigeria, and India, typically associated with tropical environments. As with several other exotic cockroach species, its spread beyond its native range is likely facilitated by international plant trade and shipping activities.

The Maltese cockroach (*Ectobius melitensis* Bohn & Sciberras 2021) is a cockroach species endemic to the Maltese Islands. Collected first in 2010, formally described in 2021 by entomologists Horst Bohn and Arnold Sciberras. This species was found in tufts of grass, preferably in those of *Hyparrhenia hirta* (L.) Stapf. At places where the species occurred most larger tufts were inhabited, each usually by a number of specimens. Occasionally, tufts of other grass species, as for example, *Lygeum spartum* L., were also colonized, however, in much less density. The distribution of *E. melitensis* in Malta is restricted to a relatively narrow band extending along the southern coast of Malta, between Ras ir-Raheb (at the western end of the Victoria Lines) as far as to the Delimara peninsula. There is only one locality at some distance from the coast known as Chadwick Lakes. The absence of the species further inland may be due to the rarity of the favorite grass in this region. Themissing of the species in other regions of the island, north of the Victoria Lines, presumably has other reasons since there are extended areas with *H. hirta*. This species belongs to the *kraussianus*-species group within the Ectobius genus. This group is known from Sicily and surrounding islands such as Ustica, the Aeolian Islands, and Ponza, with one species also reaching Albania. The discovery of E. melitensis expanded the known cockroach fauna of the Maltese Archipelago, highlighting the region's unique biodiversity. The holotype specimen *of E. melitensis* was collected at Għar Lapsi, located southwest of Siġġiewi in Malta.

The Asian cockroach (*Blattella asahinai* Mizukubo, 1981) was first recorded in Malta in 2024 during a hotel pest management intervention targeting German cockroaches (Blattella germanica). These two species are morphologically very similar, making them difficult to distinguish through appearance alone.

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However, *B. asahinai* was identified based on its distinct behavior and habitat preferences. Unlike the German cockroach, which is primarily an indoor species, B. asahinai exhibits a strong tendency to be found outdoors, a key characteristic that facilitated its detection. This species is native to Southeast Asia but has successfully expanded its range to various other regions, including parts of the southern United States, where it has become an established pest. The species thrives in warm, humid environments and is particularly well adapted to outdoor habitats, unlike its close relative, the German cockroach. Its ability to disperse efficiently and its preference for light sources make it a challenge for pest control efforts in newly invaded regions. This species was recently documented as part of an ongoing study on the cockroach fauna of Malta. The study also includes the Maltese nomenclature for all cockroach species, contributing to a better understanding of the islanders Interaction with this group of insects. This species was recorded the first in the Maltese islands in this current work.

In March 2025, a male Tawny cockroach (*Ectobius pallidus* Olivier, 1789) was documented for the first time in Malta, specifically in a locality known as Pembroke. This coastal area, characterized by garigue and open shrubland, provides suitable habitats for this species. Given the prevailing meteorological conditions at the time, it is plausible that the specimen arrived from Libya (although species is not recorded there but high probability that it exists there). On March 21st, Malta experienced a Scirocco wind event with winds originating from the southeast in the morning and shifting to a southerly direction in the afternoon. Wind speeds were recorded at force 5–6, with stronger gusts, making long-distance passive transport of lightweight insects such as this species feasible. The species' ability to fly, combined with its small size, increases the likelihood that it was carried over the Mediterranean from North Africa. The discovery in Pembroke marks the first confirmed record of this species in Malta. Further monitoring will be necessary to determine whether *E. pallidus* has established a population on the island or if this individual represents a one-time introduction via windborne dispersal. This species native to Europe, North Africa, and parts of western Asia. Its range extends from the Mediterranean region into Central and Northern Europe, where it has been expanding due to climate change and human activity. Unlike some other cockroach species, E. pallidus is primarily an outdoor insect, preferring grasslands, woodlands, and shrubby areas rather than human dwellings. In Europe, it has been widely documented in countries such as: France, Germany, United Kingdom (where it was introduced and spread rapidly) Spain, Italy, Greece and the Balkans. In North Africa, E. pallidus has been recorded in: Morocco, Algeria, Tunisia, Libya. Additionally, it has been observed in Turkey and parts of the Middle East, suggesting an adaptive range that extends beyond its core Mediterranean distribution. This species was recorded the first in the Maltese islands in this current work.

VII. Ecological and Cultural Impact

Cockroaches have long been associated with human habitation, often considered pests due to their ability to spread pathogens and their resilience to control measures. However, some species play beneficial roles in the ecosystem, breaking down organic matter and contributing to nutrient cycling. In Malta, cockroach infestations are a common concern in urban and suburban areas, particularly during the warm summer months. Public health authorities have implemented control measures, including sanitation campaigns and pesticide applications, to manage populations.

VIII. Conclusion

The cockroach species present in the Maltese Islands reflect a complex history of natural dispersal and human-mediated introductions. From ancient trade routes to modern globalization, these resilient insects have adapted to Malta's unique environment. Continued monitoring and documentation of cockroach species are essential to understanding their ecological roles and managing potential public health risks. Further research may uncover additional species or provide deeper insights into the historical pathways that brought these insects to the islands.

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Navigating Water Scarcity and Ecological Change: A Synthesis of Modern Hydrologic and Rangeland Management in the American Southwest

By Dr. Cameron Dorsett

Introduction- The arid and semi-arid rangelands of the American Southwest are defined by inherent water scarcity, characterized by irregular rainfall patterns and the intermittent presence of water. This makes water a critical limiting resource for all biological activity within these ecosystems. The unique hydrological regime profoundly influences the structure and function of these environments, impacting everything from the distribution and composition of vegetation to wildlife habitat and overall ecosystem health.

These landscapes face a complex interplay of challenges, including significant hydrologic alterations, ecological degradation, and evolving socio-economic dynamics. Specific problems observed include the proliferation of gully and arroyo formation, extensive woody plant encroachment, and the decline of native floodplain grasslands. Historical human activities, such as past grazing practices and the construction of water control structures, have significantly contributed to these alterations, often leading to unintended consequences like disconnected floodplains and increased erosion.

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Navigating Water Scarcity and Ecological Change: A Synthesis of Modern Hydrologic and Rangeland Management in the American Southwest

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I. Introduction: The Critical Nexus of Water and Rangelands in Arid Environments

The arid and semi-arid rangelands of the American Southwest are defined by inherent water scarcity, characterized by irregular rainfall patterns and the intermittent presence of water. This makes water a critical limiting resource for all biological activity within these ecosystems. The unique hydrological regime profoundly influences the structure and function of these environments, impacting everything from the distribution and composition of vegetation to wildlife habitat and overall ecosystem health.

These landscapes face a complex interplay of challenges, including significant hydrologic alterations, ecological degradation, and evolving socio-economic dynamics. Specific problems observed include the proliferation of gully and arroyo formation, extensive woody plant encroachment, and the decline of native floodplain grasslands. Historical human activities, such as past grazing practices and the construction of water control structures, have significantly contributed to these alterations, often leading to unintended consequences like disconnected floodplains and increased erosion.

The documents collectively demonstrate that while aridity is a natural condition, human activities have substantially amplified and redirected the impacts of water scarcity, leading to more severe and widespread ecological degradation, such as arroyo formation and floodplain disconnection. For instance, hydrologic connectivity issues have become prevalent on the Buenos Aires National Wildlife Refuge (BANWR) due to the advancement of altered drainage pathways through channel incision and arroyo formation. Many of these incised channels likely developed as a result of failed water retention and diversion structures installed by the U.S. Soil Conservation Service (SCS) in the early 1900s. This direct causal linkage, repeatedly emphasized across the available information, highlights that human interventions, even those initially intended for conservation or resource management, have become significant drivers of the very problems they sought to address or mitigate. This implies that effective solutions must target both natural processes and the legacy of human impact.

The framing of the problem as a critical nexus of interconnected challenges implicitly advocates for an interdisciplinary approach to solutions, moving beyond siloed management within hydrology, ecology, or socio-economics. Rangeland ecohydrology, an emerging field, specifically deals with the intricate relationship between rangeland ecosystems and the hydrologic processes that affect them. An integrated framework for science-based arid land management positions hydrologic function as foundational to biotic integrity and the provision of ecosystem services. The problems detailed, such as failed infrastructure leading to ecological decline, the complex impacts of mesquite encroachment, and the social aspects of water rights, are inherently multifaceted. Therefore, effective solutions cannot arise from a single discipline but necessitate a synthesis of hydrological science, ecological understanding, and socioeconomic realities.

This review aims to synthesize findings from recent research to explore the multifaceted issues at the intersection of rangeland ecosystems, hydrologic processes, and human management in the American Southwest. It integrates insights from detailed hydrologic engineering analyses of failed infrastructure, modern ecohydrological methodologies for assessment and modeling, and the evolving socio-economic and policy dimensions of water resource management. The goal is to provide a comprehensive, expert-level understanding for researchers, land managers, and policymakers seeking to foster resilience and sustainability in these vital, water-limited landscapes.

II. Hydrologic Dynamics and Infrastructure Challenges

a) *Water Control Structures and Their Vulnerability*

Historically, various water control structures, including concrete drop spillways, earthen spreader berms, and dirt stock tanks, were constructed on rangelands, often with limited hydraulic design considerations. These structures aimed to manage floodwaters for purposes such as increased forage production or livestock watering. However, many have failed over the past 60-70 years due to inadequate

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design and/or a lack of maintenance, leading to detrimental outcomes such as increased arroyo downcutting and disconnectedness of floodplain grasslands.

b) Case Study: Banwr Spillway Failure

A detailed hydrologic engineering analysis was conducted on a failed concrete drop spillway (broad-crested weir) at the outlet of the Buenos Aires National Wildlife Refuge (BANWR) watershed southwest of Tucson, AZ. The primary objective of this analysis was to determine the maximum flow the structure could pass without failure (discharge capacity) and to identify the rainfall recurrence interval and duration that would result in a flood magnitude exceeding the spillway's capacity, thus likely leading to its failure.

The methodology involved utilizing high-resolution remotely-sensed LiDAR data (from 2015) obtained from the Pima County Flood Control District and the Pima Association of Governments. This data was processed in ArcMap 10.5.1 to create a 1-meter digital elevation model (DEM). This DEM was then used to delineate the watershed, identifying the concrete spillway as the outlet or "pour point." The resulting 1501-hectare watershed was further divided into three sub-watersheds: A (94.2 ha), B (122 ha), and C (1285 ha). Field measurements of the spillway's crest length (L=13.4m) and the maximum hydraulic head (H=0.95m), representing the depth of the weir "notch," were taken using a self-leveling level. These measurements were applied to the broad-crested weir formula (q=CLH3/2) with a weir coefficient (C) of 1.70, yielding a maximum spillway carrying capacity of 21.1 m^3/s.

Peak runoff rates from the watershed were estimated using two distinct methods: the Rational Method and the US-Soil Conservation Service (now NRCS) Curve Number (CN) Method, implemented via the Wildcat5 software. The Rational Method (qp=360ciA) required inputs of rainfall intensity and storm duration, with runoff coefficients estimated based on soil type, basin slope, and area composition. Time of concentration (tc) for each sub-watershed was calculated using the Kirpich formula. The Curve Number Method, the basis for runoff volume estimation and hydrograph generation (Q=P+0.8S(P−0.2S)2), utilized precipitation depth and a soil water retention parameter (S) derived from the Curve Number. Wildcat5 also allowed for routing design storms through a small upstream reservoir with an average surface area of 0.427 ha.

The findings on spillway capacity exceedance were significant. Based on the Rational Method, the spillway capacity was found to be adequate for runoff volumes generated within either Subwatershed A (94.2 ha) or Sub-watershed B (122 ha) individually, with peak runoff rates well below 21.1 m^3/s. However, runoff from Sub-watershed C (1285 ha) consistently exceeded capacity. A 10-year return period rainfall event with a duration of 177 minutes (2.95 hours) yielded a peak discharge of 22.8 m^3/s, surpassing the 21.1 m^3/s capacity. A 25-year return period rainfall of the same duration resulted in an even higher 27.4 m^3/s peak discharge. When considering the entire 1501-ha study site watershed, a 10-year return period rainfall of 177 minutes generated a peak discharge of 26.4 m^3/s, also exceeding capacity.

The Curve Number Method (Wildcat5) results, which allow for the generation of runoff hydrographs and routing through the upstream reservoir, further confirmed the vulnerability of the spillway. For Sub-watershed C, a 10-year return period rainfall of 24-hour duration, after reservoir routing, yielded a peak runoff flowrate of 35.4 m^3/s. For the entire 1501-ha watershed, a 10-year return period rainfall of 24-hour duration generated a peak flood of 42.0 m^3/s, which, even after routing through the reservoir, remained significantly above capacity at 41.6 m^3/s.

The comparison between the Rational Method and the Curve Number (Wildcat5) Method results highlights that longer-duration, larger-spatial-extent storms, even at lower recurrence intervals, pose a greater threat to infrastructure than shorter, more intense storms over smaller areas. The Rational Method, focusing on peak intensity at the time of concentration, might significantly underestimate the total volume and sustained flow that a structure needs to withstand. For Subwatershed C, the 10-year Rational Method peak was 22.8 m^3/s based on a 177-minute duration, whereas the 10-year, 24-hour Wildcat5 peak *after routing* was 35.4 m^3/s. This substantial difference (over 50% higher) for the same recurrence interval indicates that the longer duration and the ability to model the full hydrograph, rather than just the peak, capture a more complete picture of the flood event's impact. This implies that design considerations solely based on peak intensity from localized, short-duration storms might be insufficient for larger watersheds or regions experiencing more prolonged rainfall events, leading to a systemic underestimation of flood risk.

The consistent failure of the spillway under conditions involving Sub-watershed C or the entire watershed, despite being adequate for smaller sub-watersheds, points to a fundamental design flaw related to the scale of the contributing drainage area. This suggests that the original design likely did not adequately account for large-scale, spatially extensive rainfall events, or that the watershed characteristics (e.g., runoff coefficients, land cover) have changed over time, altering runoff generation. The inadequacy for larger contributing areas implies that the "pour point" design was either undersized for the actual area it was meant to manage, or that the assumptions about runoff generation for the larger areas were incorrect or became

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outdated. This has broader implications for infrastructure planning in dynamic rangeland environments, where land use changes, vegetation shifts, or climate variability can significantly alter runoff characteristics over decades, rendering older designs obsolete.

Table 1: Summary of BANWR Spillway Discharge Capacity and Peak Runoff Rates

Watershed	Area (ha)	Calculated Time of Concentration (min/hr)	Rational Method Peak Runoff (m^3/s)	Wildcat5 Peak Runoff (m^3/s) (Routed)
Spillway Capacity	-	-	**21.1**	**21.1**
Sub-watershed A	94.2	65.1 min (1.09 hr)	10-yr: 3.24; 25-yr: 3.85	Not presented (below capacity)
Sub-watershed B	122	46.5 min (0.77 hr)	10-yr: 6.11; 25-yr: 7.29	Not presented (below capacity)
Sub-watershed C	1285	176.9 min (2.95 hr)	10-yr: 22.8; 25yr: 27.4	10-yr (24-hr): 35.4
Entire 1501-ha Watershed	1501	176.9 min (2.95 hr)	10-yr: 26.4; 25yr: 31.6	10-yr (24-hr): 41.6

Note: Values in bold indicate peak runoff rates exceeding the spillway's capacity of 21.1 m^3/s.

Wildcat5 results for A and B were not presented in the source as they did not exceed capacity

c) Gully and Arroyo Formation

The failure of water control structures directly contributes to increased arroyo downcutting and the disconnectedness of grasslands from their floodplains. This process of gully formation, also attributed to overgrazing, high-intensity flooding, and failed man-made structures, has profound and detrimental effects on both ground-water and surface-water interactions, as well as riparian vegetation. Historical analyses, such as those for the San Pedro River, reveal a temporal link between arroyo formation, landscape changes, and declining groundwater levels, directly impacting vegetation dynamics like sacaton and mesquite.

The temporal progression of arroyo formation and its consequences illustrates a critical negative feedback loop: arroyo cutting lowers the groundwater table, which in turn disconnects riparian vegetation, such as sacaton, from its vital water source. This leads to the decline of these grasses and potentially further exacerbates erosion, creating a self-reinforcing cycle of degradation. Historical depictions show that initial conditions (pre-1880) featured a high groundwater table supporting sacaton grassland. Subsequent stages, including initial downcutting (1880-1920) and widening (1920-1940), illustrate the groundwater table dropping, leading to the replacement of sacaton grassland by barren land or mesquite. This demonstrates a direct causal chain: physical alteration (arroyo cutting) leads to hydrological change (groundwater decline), which then causes ecological change (vegetation shift), which in turn can further promote erosion by reducing ground cover. This understanding is crucial for comprehending the persistence and severity of rangeland degradation.

The Universal Soil Loss Equation (USLE: A=RKLSCP) is a widely used tool to quantify gully formation and sediment erosion, providing a framework for understanding the factors contributing to soil loss. This equation helps in assessing estimated soil loss based on rainfall erosivity, soil erodibility, slope-length gradient, cover and management, and erosion control practices.

The decline of sacaton grasslands and the proliferation of arroyos are not isolated issues but are deeply intertwined through the concept of hydrologic connectivity. The incised channels disconnect the sacaton floodplain from available runoff, preventing the ideal inundation that these grasses require. This implies that restoring sacaton and other riparian vegetation requires not just planting, but fundamentally re-establishing the *hydrologic pathways* and surface ground water interactions that support them. The problem is not merely a lack of water overall, but a

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misdistribution of water due to altered flow paths. Therefore, effective management must focus on restoring this natural hydrologic connectivity, possibly through methods like earthen dikes and water spreaders, to ensure water reaches the areas where it is most ecologically beneficial for floodplain health.

III. Ecological Responses to Hydrologic Alterations

a) Vegetation Shifts and Hydrologic Connectivity

The American Southwest has experienced significant vegetation change, including a notable decline in native grasses like Big sacaton (Sporobolus wrightii) and Alkali sacaton (Sporobolus airoides), which historically dominated riparian floodplains. This decline is intimately linked to issues of hydrologic connectivity, where channel incision and arroyo formation disconnect floodplains from available runoff, thereby preventing the crucial inundation necessary for sacaton health. Other contributing factors to this decline include past grazing methods, agricultural crop conversion, channelization for irrigation, and residential development.

The decline of sacaton grasslands, which historically "trapped sediment, spread water like a dam, and leveled valley bottoms," represents not just a change in species composition but a significant loss of natural hydrologic regulation. When these grasses decline, the landscape loses a natural mechanism for sediment retention and water spreading. This directly impacts the ability of floodplains to retain water and prevent channelization, thus contributing to the very arroyo formation and disconnectedness that initially harmed the sacaton. This indicates that the vegetation itself acts as an "ecosystem engineer" that actively shapes hydrology, and its loss has cascading negative effects on water management.

Modern methods for assessing the ecological state of riparian sacaton stands and grasslands include the use of State-and-Transition Models (STMs), remote sensing, field verification, and consultation of expert opinion. STMs, for example, serve to classify vegetation by type, state, and canopy cover, aiding in the understanding of complex ecological dynamics.

The acknowledgment of ongoing debate regarding the leading cause of these phenomena (i.e., humans, climatic factors), alongside evidence of failed SCS structures, and overgrazing, suggests that current rangeland degradation is a complex outcome of both climatic variability and longterm anthropogenic impacts. While climate provides the backdrop, human land use and infrastructure decisions have profoundly altered the system's response to natural climatic events, making the problem a socio-ecological one that requires multi-factor management strategies rather than simplistic solutions.

b) Woody Plant Encroachment

Over the last century, woody plant encroachment, particularly by mesquite, has significantly increased in grassland savannas. This phenomenon has complex and often controversial effects on the ecosystem water budget.

Studies on the Santa Rita Experimental Range (SRER) utilized a water balance equation ($dS/dt = P - Q - AET - L$) to quantify annual water balance, where dS/dt is the change in soil moisture, P is precipitation, Q is runoff, AET is actual evapotranspiration, and L is percolation. Experimental treatments involving mesquite removal showed that while removal *can* decrease watershed runoff, differences in soil properties among study sites had a *greater* effect on surface hydrology. This finding is a critical nuance, as it implies that broad-scale shrub removal might not always yield the desired hydrologic benefits if underlying soil degradation or inherent soil characteristics are not addressed. This challenges a simplistic "remove shrubs to get more water" narrative and emphasizes the need for site-specific assessments, as the physical characteristics of the soil might be more influential in determining water movement than the presence or absence of a particular vegetation type.

While often perceived as detrimental, some studies suggest shrub encroachment may not always be negative. Research in semi-arid rangelands has shown that shrub removal does not always significantly improve the water budget. In some cases, shrub encroachment can even reverse desertification by creating "islands of fertility" with enhanced water budgets. This concept introduces a potential positive feedback loop where shrubs, despite consuming water, might locally improve soil conditions and water retention, thereby facilitating other plant growth. This suggests that the ecological role of woody plants in arid systems is more complex than simply being "water consumers" and might involve ecosystem engineering functions that enhance overall site productivity and resilience in certain contexts. This shifts the perspective from simple eradication to understanding the context-dependent functional role of these plants, suggesting a need for more nuanced management strategies that consider their potential benefits.

c) Wildlife Water Developments

Since the mid-20th century, thousands of artificial water sources, such as guzzlers, stock tanks, and modified natural tanks, have been constructed across the American West. These developments have, in many cases, successfully expanded the distribution and abundance of various wildlife species, including both game (e.g., deer, elk, quail) and non-game animals (e.g., bats, amphibians).

However, the practice of developing artificial water sources is not without its critics and is considered

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a "double-edged sword". Concerns have been raised about potential negative impacts, including increased predation (with sites potentially functioning as "predation sinks"), heightened competition between native and non-native species, the accelerated spread of disease, and direct mortality from animals becoming trapped in water structures. The "predation sinks" hypothesis suggests that an intervention designed to benefit wildlife (by providing water) can inadvertently create an ecological trap, where the concentration of animals at these sites makes them more vulnerable to predators. This highlights the complex and often unpredictable consequences of single-species or single-factor management interventions in interconnected ecosystems.

While much of the evidence for these negative impacts remains anecdotal, it highlights the critical need for more rigorous planning, monitoring, and research to ensure that wildlife water developments achieve their intended benefits without causing unintended harm. The prevalence of anecdotal evidence for negative impacts suggests a significant gap in rigorous scientific evaluation of these widespread interventions. This calls for more systematic, long-term monitoring and research to move beyond assumptions and inform truly evidence-based conservation practices, ensuring that management decisions are grounded in comprehensive understanding rather than limited observations.

IV. Modern Methodologies for Rangeland Ecohydrology and Management

a) Integrated Data Collection and Analysis

Modern ecohydrology heavily relies on advanced technologies for data collection and analysis, enabling researchers to bridge the gap of large spatiality and investigate water budget changes over extended periods.

High-resolution remotely-sensed LiDAR data (flyover in 2015) and available historic aerial imagery (dating as early as 1936) are processed in Geographic Information System (GIS) software, such as ArcMap and Google Earth Pro. This allows for the creation of 1-meter digital elevation models (DEMs), precise delineation of watersheds and sub-watersheds, and detailed mapping of vegetation distribution and soil types. This capability enables fine-tuned analysis of hydrologic networks and ecological conditions at scales previously unattainable. The integration of remote sensing (LiDAR, aerial imagery) with GIS for watershed delineation and vegetation/soil mapping represents a transformative shift from traditional, labor-intensive field surveys to a more efficient, large-scale, and spatially explicit understanding of rangeland conditions. This enables a more precise application of hydrologic models and State-andTransition Models (STMs).

Software packages such as the Automated Geospatial Watershed Assessment tool (AGWA), the Rangeland Hydrology and Erosion Model (RHEM), KINEROS2, the Soil and Water Assessment Tool (SWAT), and Wildcat5 are extensively utilized. These models predict peak flow, runoff volumes, and develop storm hydrographs by integrating spatially explicit land cover, soil type, and precipitation datasets. The significant reliance on modeling in ecohydrology research (34% of studies) indicates a recognition that direct experimentation or observation alone is often insufficient to fully understand complex, large-scale, and long-term hydrologic processes in rangelands. Models allow for invaluable scenario testing, such as different storm recurrence intervals, land cover changes, and management interventions, which would be impossible or impractical in the real world, thus informing adaptive management decisions more effectively. Models serve as virtual laboratories, enabling the exploration of "what-if" scenarios, which is crucial for developing proactive and resilient management strategies in environments characterized by high variability and uncertainty.

b) State-and-Transition Models (STMs)

State-and-Transition Models (STMs) are a fundamental land management approach first developed by the Natural Resources Conservation Service (NRCS) that aids managers in understanding complex ecosystem dynamics, particularly in semi-arid and arid lands. They describe non-linear vegetation dynamics and ecological shifts between different "states".

STMs are defined by key elements: "states" (suites of temporally-related plant communities and associated dynamic soil properties), "community phases" (distinctive plant communities within a state), "transitions" (mechanisms transforming one state into another), "triggers" (events initiating transitions), and "thresholds" (conditions that distinguish alternative states and preclude unassisted recovery of the former state). For instance, an STM can depict a shift from sacaton grassland to a "Dry" grassland due to processes like gullying and altered surface water pathways, with repair methods such as water spreaders as potential interventions.

Developing STMs involves an iterative, systematic approach, often an eight-step process. This generally follows from the creation of basic concepts based on literature and expert workshops, to refining concepts, categorizing regions based on soils and topography, developing inventories of plants and soils, housing data in databases, building and analyzing initial models, and finally characterizing and monitoring "states".

STMs are often described as "resilience-based," illustrating how ecosystems move between current and alternative states, potentially crossing "thresholds"

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guided by positive and negative feedbacks. Understanding these thresholds is crucial for preventing irreversible degradation, as crossing them implies a shift past critical levels of herbivory, vegetation cover, or soil loss, disrupting ecosystem dynamics and structure. The concept of "thresholds" is critical because it implies that degradation is not always linear or easily reversible. Once a threshold is crossed (e.g., due to critical soil loss or altered hydrologic function), the ecosystem may not recover naturally, often requiring costly and active restoration efforts. This highlights the importance of early intervention and proactive management to prevent irreversible shifts, as managing to stay within a desired state is far more effective and economically viable than attempting to reverse a degraded state through expensive restoration.

Recent advancements integrate remote sensing with STMs to link ecosystem services with state transitions. This allows managers to evaluate management decisions based on the net flow of ecosystem services (positive services minus negative services), facilitating the development of "best management practices" (BMPs) by mapping ecological sites and states based on soil type and vegetation cover. The integration of remote sensing with STMs to link ecosystem services to management decisions represents a sophisticated evolution of rangeland management. It moves beyond simply tracking ecological changes to explicitly quantifying the human benefits (or costs) associated with different land management choices, providing a stronger economic and social justification for conservation and restoration efforts. This advancement allows managers to make decisions not just based on ecological health metrics, but on the value that healthy ecosystems provide to society (e.g., water quality, forage, wildlife habitat, recreation). This provides a powerful argument for sustainable practices by demonstrating their tangible benefits to human well-being and economic prosperity, thereby engaging a broader range of stakeholders.

Table 2: Key Concepts and Application of State-and-Transition Models (STMs)

STM Key Element	Definition
State	A suite of temporally-related plant communities and associated dynamic soil properties that produce persistent characteristic structural and functional ecosystem attributes.
Reference State	The state supporting the largest array of potential ecosystem services and from which all other states and phases can be derived; often considered to represent a historical or natural range of variability of the set of conditions most preferred by a society.
Community Phases	Distinctive plant communities and associated dynamic soil property levels that can occur over time within a state.
Transition	The mechanisms by which one state is transformed into another state.
Trigger	Events, processes, and drivers that initiate a transition to an alternative state. Triggers can be indicated by changes in plant community patterns that result in altered feedbacks or increased risk of sudden transition from the at-risk phase.
Threshold	Conditions defined by vegetation/soil characteristics and related processes that distinguish alternative states and that preclude autogenic (unassisted) recovery of the former state.

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STM Development Process (8 Steps)	Key Tasks and Considerations
1. Develop initial ecological site concepts and STMs	Review general ecosystem models, conduct literature review, hold expert workshops/interviews; specify functionally-important soil properties; specify transient vs. persistent changes in vegetation; consider scale and spatial context in transitions.
2. Complete low-intensity survey	Explore relationships among states, landforms, land uses, and soils across the project area; refine strata for medium-intensity inventory.
3. Hierarchically stratify the region	Assemble digital maps and remotely sensed imagery, link to low-intensity data; delineate or recognize climate zones, soil-geomorphic systems, soil units, states, and key differences in patch structure.
4. Complete medium-intensity survey	Sample vegetation, soils, and indicators across soilgeomorphic systems, ecological sites, and state strata/gradients and at many points.
5. House data in database	Database allows soil, landform, and vegetation data to be related to one another.
6. Conduct exploratory analyses and tests of relationships	Use scatterplots, model building, quantile regression, and multivariate analysis to explore data and to test specific propositions derived from ecological sites and STMs.
7. Refine ecological site and STM concepts	Based on analyses and synthesis of literature, modify ecological site classes, modify initial STMs, quantify characteristics of ecological sites and states.
8. Complete high-intensity characterization and initiate monitoring	Generate statistical samples, especially for reference states, and collect precise information on vegetation and dynamic soil properties to establish characteristic values; monitor points to document dynamics of the state.
Source:	

c) Experimental Interventions

To combat groundwater decline and soil erosion, past management methods have involved the implementation of earthen dikes and water spreaders to retain runoff, increase grass production, and enhance soil moisture distribution. Furthermore, experimental "irrigation" or simulated precipitation pulses have been studied to understand vegetation and soil response.

Precipitation pulses are highly valuable for arid-land systems, acting as important agents for biological activity. One phenomenon that arises due to infrequent precipitation pulses is that of hydraulic redistribution, which involves plant roots taking up moisture from deeper or wetter soil areas and actively redistributing it to drier soil zones. This reveals a sophisticated, often unseen, mechanism by which plants in arid environments actively optimize water use and potentially influence soil moisture beyond their immediate root zone. This indicates that the role of vegetation in the water cycle is not just about passive uptake and transpiration, but also active redistribution, which could have significant implications for soil health, nutrient cycling, and the survival of other plants in water-limited systems. This understanding is crucial for developing more effective restoration strategies, as it suggests that promoting certain plant species might indirectly improve overall soil moisture conditions and support other vegetation.

Controlled studies, such as one focusing on Mesquite sap flow and soil water content response after

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a 50 mm irrigation application, showed an initial increase in soil water content followed by a plateau. Similarly, experimental precipitation addition (39 mm) on the SRER resulted in increased soil moisture content and decreased soil temperatures in all cases, with implications for mesquite establishment. These experimental irrigation studies provide crucial empirical evidence for how specific precipitation pulses translate into measurable soil moisture dynamics and plant physiological responses. This data is vital for validating hydrologic models, calibrating water balance equations, and designing effective, targeted water harvesting or supplemental irrigation strategies in restoration efforts, moving from theoretical understanding to practical application. Such controlled experiments are essential for establishing cause-and-effect relationships in ecohydrology, and this type of data is critical for refining predictive models and for developing practical, evidence-based interventions, such as determining the optimal timing and amount of water needed for successful plant establishment or for enhancing soil moisture in degraded areas.

V. Socio-Economic and Policy Dimensions of Water Management

a) Evolving Land Ownership and Management Paradigms

A significant trend reshaping the western landscape is the transition of ranch ownership from traditional ranching families to a new cohort of "amenity buyers". These new owners are often not dependent on the ranch for income and are drawn to the land primarily for its recreational and environmental values. This shift is particularly pronounced in high-amenity areas, such as southwestern Montana, where world-class fisheries have fueled a real estate boom.

New ranch owners typically bring a different set of priorities and approaches to land and water management compared to longtime owners. They are more likely to engage in practices such as riparian and aquatic ecosystem restoration, reallocating water to instream uses to benefit fish, and constructing private fish ponds for recreational purposes. While restoration efforts (e.g., planting willows, restoring natural stream channels) can significantly improve habitat and mitigate dewatered streams, the proliferation of private fish ponds poses a number of risks to native and wild fisheries, including the spread of disease and invasive species, thermal pollution, and the disruption of natural hydrologic processes.

The contrast between traditional ranching practices (e.g., flood irrigation for forage/habitat) and "amenity buyer" practices (e.g., instream flow reallocation, private fish ponds) reveals a fundamental tension between different land use values and their associated conservation goals. Traditional ranching often integrates water management with livestock production and broader ecosystem services, such as maintaining wet meadows, while amenity buyers may prioritize specific recreational (fishing) or aesthetic environmental values, sometimes leading to unintended negative consequences (e.g., from private fish ponds). This highlights that "conservation" itself can be defined and pursued in conflicting ways, creating challenges for integrated land and water management.

The rise of "amenity buyers" introduces new economic drivers into rangeland water management, where land value is increasingly tied to recreational and aesthetic attributes rather than solely agricultural productivity. This can lead to market-driven shifts in water allocation and land use that are not necessarily aligned with broader ecological sustainability or traditional community values, necessitating new policy approaches. The economic incentive for land ownership has shifted from agricultural production, which historically dictated water use under prior appropriation, to non-consumptive or recreational uses. This economic shift can drive water management decisions, such as building private fish ponds, that may conflict with existing water rights, ecological needs, or the practices of neighboring traditional ranchers. This necessitates new policy frameworks that can mediate these diverse economic and social pressures.

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Table 3: Comparison of Water Management Practices by Landowner Type in the American West

Category	Traditional Ranching Families	Amenity Buyers
Primary Motivation for Land Ownership	Income from ranching, Cultural traditions, Commitment to ranching lifestyle	Recreational/Environmental values, Not dependent on ranch for income
Typical Water Management Practices	Flood irrigation (long-standing tradition), Off-stream water and salt placement for livestock distribution	Riparian and aquatic ecosystem restoration, Reallocating water to instream uses (for fish), Constructing private fish ponds
Key Benefits (Observed/Stated)	Vital forage for livestock, Habitat for wildlife, Groundwater recharge, Late-season flows benefiting fish habitat, Improved livestock distribution, Increased cattle weight gains	Improved fish habitat, Aesthetic/recreational value, Enhanced riparian health
Potential Unintended Consequences/Concerns	Perceived as "inefficient" by modern standards	Risks to native/wild fisheries (disease, invasive species, thermal pollution), Disruption of natural hydrologic processes, Concentration of animals (predation sinks, disease spread)
Source:		

b) The "Efficiency" Paradox in Irrigation

Flood irrigation, a long-standing tradition in the American West, involves spreading water across fields through ditches and pipes, mimicking natural flooding processes. This practice plays a crucial role in maintaining wet meadows, which provide vital forage for livestock and habitat for a wide array of wildlife. It also contributes to groundwater recharge and the creation of lateseason flows beneficial for fish habitat. However, flood irrigation is often perceived as "inefficient" compared to more modern techniques like sprinkler and center-pivot irrigation, which may use less water overall.

The definition of "efficiency" in water use is complex and often fails to account for the broader social and ecological benefits of flood irrigation. Ranchers' decisions about which irrigation methods to use are not solely driven by economic considerations; they are also influenced by a complex web of factors including the natural features of the landscape, cultural traditions, the availability of skilled labor, and a commitment to the ranching lifestyle. The "efficiency paradox" reveals a critical disconnect between a narrow, engineering-centric definition of water efficiency (i.e., minimizing water diverted or consumed) and a broader, ecohydrological understanding that encompasses multiple ecosystem services. Optimizing for one metric (water volume saved) can inadvertently degrade other valuable ecosystem functions (e.g., groundwater recharge, wetland habitat, late-season stream flows), leading to unintended negative consequences. A purely volumetric definition of "efficiency" is insufficient for complex ecological systems. This highlights that policies promoting "efficiency" without considering the full suite of ecosystem services provided by traditional practices might lead to a net loss in overall environmental and social value, necessitating a more holistic definition of water use efficiency.

The influence of cultural traditions and commitment to lifestyle on rancher decisions suggests that purely economic or technical solutions to water management challenges will likely face significant resistance and may ultimately fail. Effective policy and management strategies must integrate socio-cultural considerations and engage landowners in a way that respects their values and practices, rather than imposing top-down, technology-driven solutions. Even if a technological solution, such as sprinkler irrigation, is technically "more efficient," it might not be adopted if it conflicts with deeply held values or practical realities of the ranching community. This implies that successful

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water management requires a participatory approach that understands and addresses these socio-cultural dimensions.

d) Water Rights and Allocation

The legal framework governing water use in the American West is largely based on the doctrine of prior appropriation, which grants water rights to those who first put the water to a "beneficial use," historically meaning diversion for agriculture and other consumptive uses. However, in recent decades, there has been a growing recognition of the value of instream flows for recreation, wildlife, and ecosystem health.

While states like Montana have begun to create legal mechanisms for reallocating water from consumptive to instream uses, the process remains legally and socially contentious. As the values and priorities of landowners and society continue to evolve, there is a growing need for more flexible and adaptive legal and institutional frameworks for managing water in the West. The tension between the historical "prior appropriation" doctrine (focused on consumptive use and diversion) and the emerging recognition of "instream flows" for ecosystem health represents a fundamental legal and philosophical conflict in Western water law. This conflict directly impedes adaptive management and highlights the inertia of legal systems in responding to evolving ecological understanding and societal values. A legal system designed for one set of values (resource extraction/consumption) struggles to accommodate new values (ecosystem health, non-consumptive uses). This legal inertia creates significant barriers to implementing modern ecohydrological principles, as the existing framework is not inherently designed for ecosystem services or adaptive management.

The legal and social contentiousness of water reallocation implies that future water management solutions in the West will require significant stakeholder engagement, negotiation, and potentially new governance models that can bridge the gap between historical rights and contemporary ecological needs. This moves beyond a purely scientific or technical problem to a complex socio-political challenge. Water scarcity in the West is not just a physical or ecological problem but a deeply entrenched socio-political one, involving competing interests, historical entitlements, and deeply held values. Therefore, effective solutions must involve collaborative governance, conflict resolution, and policy innovation that can facilitate equitable and sustainable water allocation.

VI. Conclusion: Towards Integrated and Adaptive Rangeland Water Management

This synthesis underscores that rangeland water management in the American Southwest is characterized by profound and intricate interdependencies between hydrologic processes, ecological functions, and socio-economic dynamics. Failed infrastructure can exacerbate arroyo formation, directly leading to significant vegetation shifts like the decline of native sacaton grasslands. Woody plant encroachment, while often viewed negatively, has complex and context-dependent effects on water budgets. Furthermore, even well-intentioned interventions like artificial wildlife water developments, while offering benefits, pose significant ecological risks. The evolving landscape of land ownership, driven by new economic motivations, and the contentious nature of water rights further complicate effective management. Effective and sustainable rangeland management necessitates a holistic and interdisciplinary approach. This involves leveraging modern methodologies such as integrated remote sensing, GIS, and advanced hydrologic modeling for precise data collection, spatial analysis, and predictive capabilities. State-and-Transition Models (STMs) are crucial tools for understanding non-linear ecological shifts, identifying critical thresholds, and informing proactive management strategies to prevent irreversible degradation of ecosystem services.

a) Recommendations for Future Research, Policy, and Management

To navigate these complex challenges and foster resilience in the American Southwest's rangelands, the following recommendations are put forth:

i. *Research*

Future research must prioritize rigorous, long-term monitoring and evaluation of all management interventions, moving beyond anecdotal evidence to robust scientific validation. This includes a more nuanced understanding of the ecological impacts of practices like shrub removal, considering soil-vegetation interactions, and a comprehensive assessment of the full spectrum of benefits and risks associated with wildlife water developments. Further investigation into the diverse motivations and constraints of different landowner types is also vital to inform effective engagement strategies.

ii. *Policy*

Policy frameworks need to evolve to be more flexible and adaptive, specifically addressing the legal and social contentiousness inherent in water reallocation processes. The definition of "water efficiency" must expand beyond narrow volumetric metrics to encompass the broader ecological and social benefits provided by various water management practices, including traditional ones. This requires a re-evaluation of legal doctrines like prior appropriation to better accommodate contemporary ecological values and the

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evolving understanding of water's role in ecosystem health.

b) On-the-Ground Management

Practical management should prioritize restoring hydrologic connectivity to support native vegetation like sacaton, potentially through targeted interventions such as water spreaders that consider specific soil properties and the context-dependent ecological role of woody plants. Collaborative approaches involving diverse stakeholders, including traditional ranchers, amenity buyers, government agencies, and researchers, are essential to bridge differing values and ensure sustainable and equitable outcomes for water and land resources. This integrated approach recognizes that water scarcity is not merely a physical problem but a deeply entrenched sociopolitical one that requires shared governance and adaptive strategies.

The analysis implicitly argues for a fundamental paradigm shift in rangeland management: from reactive, single-issue interventions to proactive, integrated, and adaptive strategies that explicitly acknowledge the deep interconnectedness of water, land, and human systems. This requires a continuous feedback loop between scientific understanding, policy development, and on-theground practice, fostering resilience in the face of ongoing environmental and social change. The future of rangeland management depends on moving beyond addressing symptoms to transforming the underlying governance and management systems to be inherently adaptive, interdisciplinary, and responsive to the dynamic interplay of natural and human forces.

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Longitudinal and Transverse Dispersion - Diffusion in Streams: Its Effects in "Complete Mixing" Condition, and the Role a New State Function

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Abstract- In environmental impact studies on natural flows, the concept of "complete mixing" linked to the flow's "assimilation capacity" is usually presented in terms of transverse diffusion alone, ignoring the fact that it is a joint mechanism with longitudinal dispersion. This article presents a new approach in which a state function comprehensively describes how the two mechanisms act in unison, facilitating the interpretation and calculation of the "mixing length." The developed equations are applied to the study of three different channels, obtaining satisfactory results, converging with those calculated from Elder's transverse diffusion coefficient.

Keywords: *assimilation capability of streams, state functions, tracers.*

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Longitudinal and Transverse Dispersion - Diffusion in Streams: Its Effects in "Complete Mixing" Condition, and the Role a New State Function

Alfredo José Constaín Aragón

Abstract- In environmental impact studies on natural flows, the concept of "complete mixing" linked to the flow's "assimilation capacity" is usually presented in terms of transverse diffusion alone, ignoring the fact that it is a joint mechanism with longitudinal dispersion. This article presents a new approach in which a state function comprehensively describes how the two mechanisms act in unison, facilitating the interpretation and calculation of the "mixing length." The developed equations are applied to the study of three different channels, obtaining satisfactory results, converging with those calculated from Elder's transverse diffusion coefficient.

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I. Introduction

a) Paper Size, Margins, Columns and Paragraphs

For environmental impact studies, it is vital to know the dynamics of conservative solutes moving in a flow, which simulate quite well the behavior of the pollutants poured in, and are therefore important for their understanding, control and mitigation. [1] In this perspective, the calculation of the transport coefficients, especially the one that defines the transverse diffusion, is fundamental.

J. W. Elder in his original work [2], based on theoretical considerations, found a definition of the transverse diffusion coefficient, εy, which have the following definition, with H as depth, g, as acceleration of gravity and S, as slope of the energy line:

$$\varepsilon y \approx 0.23 * H * \sqrt{H * g * S} \qquad (1)$$

But later, H.B. Fischer [3], who varied this coefficient by about 50%, found better accommodation with the experimental results. This formula is used in this Article as a reference for comparing results due to its simplicity and relative accuracy.

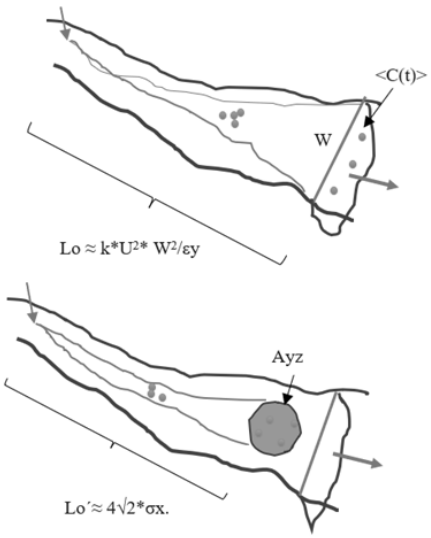
This transverse diffusion coefficient plays a very important role in understanding and defining the so-called "Mixing length", Lo, the distance at which the solute transported in a flow is considered to be "mean value" distributed in the cross section, and its concentration is a relative minimum, indicating well what the "assimilation capacity of the channel" is reached. With "k" a coefficient that depends on the way the solute is injected into the flow (k=1 for central injection), U the average velocity, and W the average width [4,5].

$$Lo \approx \frac{k*U*W^2}{\varepsilon y} \qquad (2)$$

This equation refers to the channel's "width" and is defined when the solute diffuses at an "average" value. Although the physical basis of this equation is sufficiently proven, the fact that it is affected by the "k" factor, which varies between 0.1 and 0.4 and depends on how well the injection point is located, adds an unavoidable component of imprecision.

For this reason, it is interesting to explore an alternative procedure, based on other principles, that provides greater certainty in this critical measurement.

This new procedure may be based on when the solute evenly covers the cross-section of its stream tube with a homogeneous distribution, which may or may not coincide with the channel's width. Figure 1 compares the two procedures: the classic one, corresponding to equation (2), and the new approach.



Source: Author

Figure 1: Two conditions of "complete mixing" in the evolution of a solute

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This new situation occurs when the solute transport distance is long enough for almost all of its mass (99.7%) has lost most of its interactions, and its particles are distributed homogeneously like an ideal gas (losing significantly its interactions), [6] such that, according to Gauss's Theory, there is a corresponding distance of "Six sigma", when $t \approx 4\sqrt{2} * \sigma t$, which if $U \approx \sigma_x/\sigma_t$, it holds. [7]:

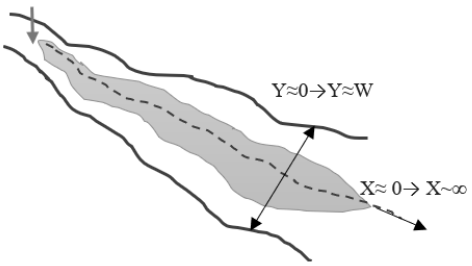
$$Lo' \approx 4\sqrt{2} * \sigma_x \quad (3)$$

Defining transverse diffusion has not been easy, as there is no identifiable velocity distribution along this axis that would allow theoretical manipulation to establish mixing along this axis, as is the case on the vertical axis. [8]

In water quality studies, this "complete mixing" condition is of primary importance, given that monitoring of the variables of interest, they must have optimal representativeness, ensuring that the models run appropriately.[9] This information is typically collected in the field with tracer tests.

On the other hand, it is necessary to distinguish diffusion from dispersion [10]. The former is associated with transport caused by turbulence as a mixing agent, and on a much smaller scale by molecular motion. The second is more directly associated with the mixing and expansion effect of a solute due to the shear effect oflongitudinal velocities, arising from the mean advective velocity. The characteristic is that both types of motion are defined as proportional to the concentration gradient.[11]

Thus, while dispersion expands without limit along the longitudinal axis, transverse diffusion has a rather small limit (restricted by a finite width). Figure 2.



Source: Author

Figure 2: Different Spatial Nature of Longitudinal and Transverse Dispersion-Diffusion

This implies that, due to this restriction, diffusion generally progresses much less rapidly than dispersion and can reach a certain equilibrium before its longitudinal portion, covering the cross-sectional area of the flow.

Then, the application of two "complete mixing" criteria must be distinguished: One: When Lo is applicable, the channel width and the transverse diffusion coefficient must be considered primarily. and Two: When Lo´ is applicable, the spatial variance of the solute curve must be considered primarily. Both criteria show important aspects of the tracer advance mechanism. The first criterion is appropriate for channels of not very great width, in which the value of "Lo" is practical for measurement. The second criterion is applied in very large rivers in which the solute behavior is well described by "Lo´", without needing to refer it to the channel width.

II. State Function to Describe the Evolution of Solutes in Turbulent Flows

a) Definition of the Function and its Relationship with the Average Flow Velocity

A transport model has been presented based not on the concept of "Dead zones" as the cause of the "non-Fickian bias" of the experimental tracer curves, but rather on the concept of heat exchange in the phenomena of "hydration" and "dilution", supported by the enthalpy of formation of the solute. [12] This evolution is described by a State Function $\Phi(t)$, fulfilling the Pfaff conditions [13] that has been applied to explain numerous experimental cases [14,15].

$$\oint d\Phi = 0 \quad (4)$$

This state function defines a one-dimensional mean flow velocity equation, similar in its quadratic structure to the Chezy-Manning mechanical equation [16]. Here $\beta \approx 0.214$.

$$U \approx \frac{1}{\Phi}\sqrt{\frac{2E}{\beta * t}} \quad (5)$$

b) Definition of the State Function in Terms of Distance

The function Φ itself is defined by clearing it from the previous equation, and putting it into function of the distance, X.

$$\Phi \approx \left(\frac{\sqrt{2E}}{U\sqrt{\beta}}\right) * \frac{1}{\sqrt{X}} \quad (6)$$

Now for two points, with X1, and $\Phi 1$, and X2 and $\Phi 2$, the following valid ratio is obtained if E does not vary significantly between each point, from eq. (5), it holds:

$$\frac{\Phi 1}{\Phi 2} \approx \frac{\sqrt{X2}}{\sqrt{X1}} \rightarrow \qquad Lo' \approx \left(\frac{\Phi 2}{0.38}\right)^2 * X2 \quad (7)$$

This equation will be useful to find distances of interest (X2) to $\Phi 2$, when $\Phi 1$ and X1 are known (this convention would be the other way around), The important thing is that the definitions are consistent with each other.

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When $\Phi 1 \approx 0.38$, then the time takes the value $Lo' \approx 4\sqrt{2}*\sigma x$, that is, the "Freedom of interactions" condition for its particles.

c) Some Thermodynamic Considerations on Interactions in Very Dilute Solutions

When the solute is suddenly injected into the flow, its mass is transformed from a "solid" compound to a "liquid" compound in a first phase, [17] by means of a heat exchange. In this phase the hydration of the solute particles occurs, by the interaction with the water dipoles. Then there is the formation of structures that respond to the Coulomb interactions between the solute particles, also with a heat exchange, until they disappear when the square root of the concentration will tend to zero, according to the Hückel-Debye law for dilute concentrations. [18] In this last phase, it can be considered that the solute particles behave almost like an ideal gas, which loses its interactions and is distributed homogeneously in the volume considered.

The tendency of these mutual interactions between solute molecules to decrease can be measured in various ways, for example with the thermodynamic equations of internal pressure, "pi" [19]:

$$\left(\frac{\partial E}{\partial v}\right)_T \approx pi \tag{8}$$

This isothermal change in the "internal energy" of the gas, E, corresponds to the interactions (mutual attraction) of the gas particles, which is very small for real gases and zero for ideal gases, if internal pressure is small (low concentrations).

But perhaps the most direct way to estimate this effect is by estimating the "braking" effect that the electrostatic interactions have on the motion of the solute plume flow. In this phase, this degraded compound behaves like "Boltzmann molecular chaos," that is, erratically in all directions and therefore without any particular structure.

d) Application of the State Function, Φ(t) to the Calculation of Ratio of Discharge, According to Two Definitions of the Parameter

If the longitudinal dispersion coefficient, E, is cleared in eq. (5) it holds:

$$E \approx \frac{\Phi^2 * U^2 * 0.214 * tp}{2} \tag{9}$$

And if it is applied to the definition of Concentration (C(t) according to Fick, [20] we have:

$$C(x,t) \approx \frac{M}{Q*\Phi*tp*1.16} * e^{\frac{(tp-t)^2}{2*0.214*(\Phi*t)^2}} \tag{10}$$

The peak concentration, Cp, is then:

$$Cp \approx \frac{M}{Q*\Phi*tp*1.16} \tag{11}$$

Therefore, the discharge, Q, is:

$$Q' \approx \frac{M}{Cp*\Phi*tp*1.16} \tag{12}$$

And according to the principle of conservation of mass we have:

$$Q \approx \frac{M}{\int_a^b C(t)dt} \tag{13}$$

If the ratio, r, between these two definitions of mass is defined as:

$$r \approx \frac{Q}{Q'} \approx \frac{\left(\frac{M}{\int_a^b C(t)dt}\right)}{\left(\frac{M}{Cp*\Phi*tp*1.16}\right)} \tag{14}$$

The average value of the solute concentration is:

$$< C(t) > \approx 0.441 * Cp \tag{15}$$

Now, if $\Phi \approx 0.38$, when $tp \approx 4\sqrt{2}*\sigma t$, and the solute particles significantly lose their interactions, and considering the mean value theorem, [21], we have:

$$r \approx \frac{\left(\frac{M}{\int_a^b C(t)dt}\right)}{\left(\frac{M}{Cp*\Phi*tp*1.16}\right)} \approx \frac{Cp*0.38*1.16}{\frac{1}{tp}\int_0^{tp} C(t)dt} \approx \frac{<C(t)>}{<C(t)>} \approx 1.0 \tag{16}$$

That is, when the "complete mixing" condition is met, the two versions of the flow are equal, that is, when the interactions of the solute particles virtually disappear.

If the solute is considered as an ideal gas, its internal pressure, "pi" must comply with Clapeyron's law, with B as a physical constant. [22]

$$\frac{pi*V}{T} \approx B \tag{17}$$

For the approximate isothermal process, it is found that as the volume of the solute plume increases (which effectively occurs due to the increase in entropy), the internal pressure (and interactions) must decrease. In this way, equation (16) is fully justified since when $\Phi \approx 0.38$ is reached, the solute plume defines a volume such that its passage in time coincides with the definition of discharge in that point.

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III. Classical Formulas for Calculating the Transverse Diffusion Coefficient, εY, and its Relationship with the Longitudinal Dispersion Coefficient, E.

The most notable antecedents of these calculations are the formulas proposed by Elder in the middle of the last century, where the two definitions depend on the "shear velocity", $u_* \approx \sqrt{(H*g*S)}$.[23]
The longitudinal coefficient proposed was:

$$E \approx 5.93 * H * u_* \quad (18)$$

And the transversal coefficient, as in eq. (1), corrected by Fischer, was:

$$\boldsymbol{\varepsilon y \approx 0.6 * H * u_*} \quad (19)$$

That is, both transport coefficients depend on the same dynamic factor, u_*.[24] Therefore, in general, the ratio of both coefficients "E/εy" can be established as a function "G" that depends on factors other than u_*, generally of an empirical, geometric or geomorphological nature, with different values depending on each author, and what factors they consider.[25]

$$\frac{E}{\varepsilon y} \approx \boldsymbol{G(several\ factors)} \quad (20)$$

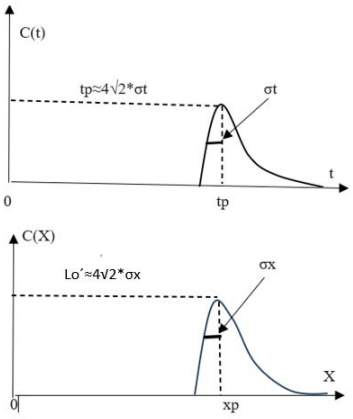
The use of u_* as the universal dynamic root to define transport coefficients is not accidental, since frictional friction is key to understanding and defining momentum transfers between turbulent fluid layers. [26]

On the other hand, it should be considered that turbulence occurs equally along the longitudinal and transverse axes, with shear advection being the predominant differentiating factor in longitudinal dispersion.

IV. Ratio between Longitudinal and Transversal Transportation as a Function of the Respective Variances

a) "Complete Mixing" Condition for Longitudinal Transport as Function of Longitudinal Variance

Longitudinal dispersion develops in an unconstrained scenario, as in Figure 3, showing how at $t \approx 4\sqrt{2}*\sigma t$, and at $Lo' \approx 4\sqrt{2}*\sigma x$, the solute reaches the condition of loss of interactions. This "complete mixing" condition for the curve is defined from the origin to the point where there *is only one time (space) variance*.

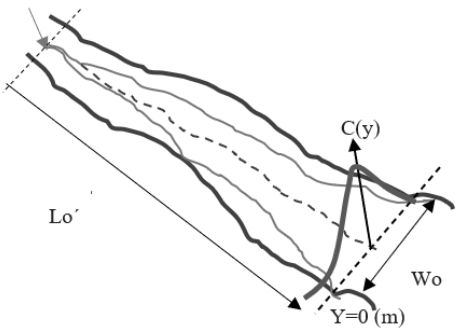


Source: Author

Figure 3: Definition of $4\sqrt{2}*\sigma x$ from 0 to only *one space variance*

b) "Complete Mixing" Condition for Transverse Transport as Function of Transverse Variance

To establish when the transverse axis transport reach the cross section homogeneously of solute tube, a similar analysis must be performed to determine how many times the transverse spatial variance, σ_y, is in the width, Wo, for the same distance Lo´. Figure 4.



Source: Author

Figure 4: Curve C(y) in Wo, at distance Lo´

The Gaussian expression in terms of the transverse spatial variance for this case is, with Cp equal in C(X) and C(Y), since $t \approx 4\sqrt{2}*\sigma t$ for both distributions , as follows

$$\boldsymbol{C(y)i \approx Cp * e^{-\frac{(y-\frac{W}{2})^2}{2*\sigma_y^2}}} \quad (21)$$

The function C(t) in this case corresponds to the inflection points of the curve.

$$\boldsymbol{C(t)i \approx 0.608 * Cp} \quad (22)$$

Therefore, eq. (21) would be put like this:

$$\boldsymbol{\frac{Cp}{C8)i} \approx e^{+\frac{(y-\frac{W}{2})^2}{2*\sigma_y^2}}} \quad (23)$$

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Rearranging:

$$\frac{1}{0.608} \approx 1.64 \approx e^{+\frac{(y-\frac{W}{2})^2}{2*\sigma_y^2}} \quad (24)$$

And then, with y=0:

$$Ln|1.64| \approx 0.50 \approx \frac{\left(\frac{W}{2}\right)^2}{2*\sigma_y^2} \approx \frac{W^2}{8*\sigma_y^2} \quad (25)$$

And then:

$$\sigma_y \approx \frac{W}{2} \quad (26)$$

Then, concurrently with eq. (3), the tracer plume, when $\Phi \approx 0.38$, transversely occupies half of the plume width. Figure 5.

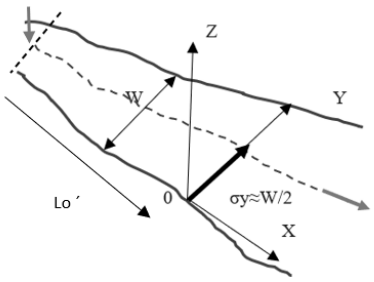


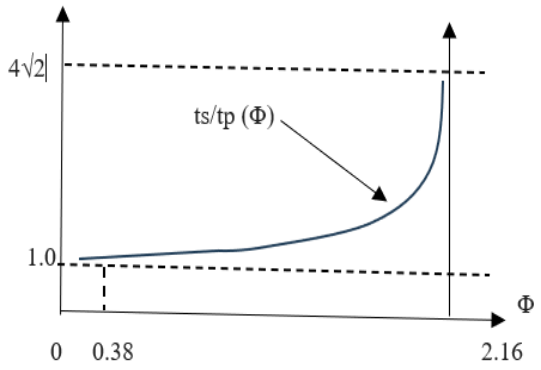
Figure 5: Occupation of ½ Flow Width by Diffusion transverse variance

Therefore, dividing the two displacements, the longitudinal and the transversal, we have:

$$\frac{\sigma_x}{\sigma_y} \sim \frac{4\sqrt{2}}{1} \approx 4\sqrt{2} \quad (27)$$

c) *Quantitative Description of this Dynamic to Find the Ratio of Centroid Time and Peak Time*

The author have already developed a successful approach for calculating the centroid-to-peak time ratio, "t_s/t_p," based on thermodynamic considerations, [27] as shown in Figure 5.



Source: Author

Figure 5: Curve of the ts/tp ratio as a function of Φ(t)

When $\Phi \approx 2.16$, the ts/tp ratio is maximum, close to $4\sqrt{2}$, which is the maximum allowed by the homogeneously distributed mass. For $\Phi < 0.38$, it asymptotically approaches 1.0, i.e., there is no delay in the solute centroid when electrostatic interactions between its particles cease. The approximate equation for this trend is:

$$\frac{ts}{tp} \approx 0.85 * \Phi^{2.2} + 1 \quad (28)$$

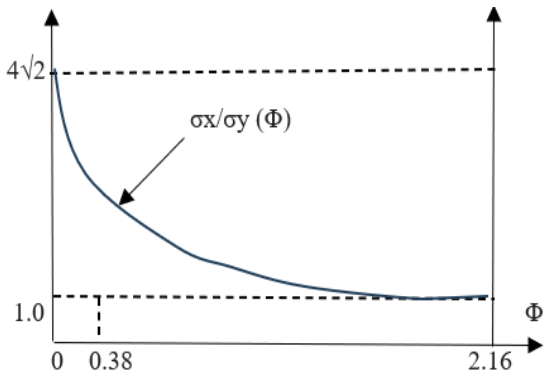
A notable value of this calculation is when $\Phi \approx 0.38$, the moment at which the solute changes to the ideal gas condition, and the electrostatic "braking" effect is reduced to a minimum:

$$\frac{ts}{tp} \approx 0.85 * 0.38^{2.2} + 1 \approx 1.10 \quad (29)$$

Which means that the centroid delay is 10%, that is, at the limit of the order of magnitude to not be considered.

d) *Quantitative Description of this Dynamic to Find the Ratio of the Transport Coefficients Σ_x and Σ_y.*

Now, based on results described in 4.2, it is interesting to find the relationship "σ_x/σ_y", which corresponding curve is as shown in Figure 6.

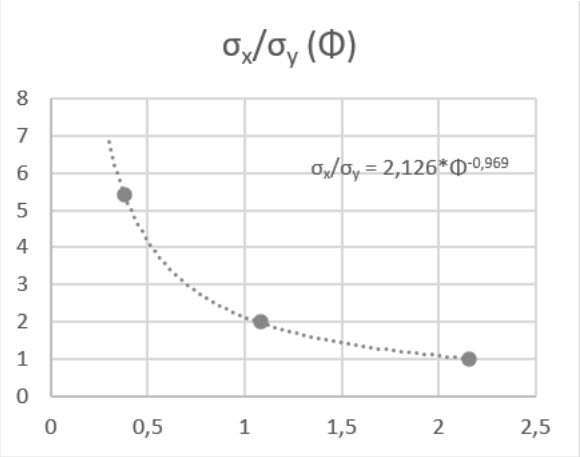


Source: Author

Figure 6: Curve of the σ_x/σ_y ratio as a function of Φ(t)

A more detailed representation, including notable modeling points, is shown in Figure 7.

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Source: Author

Figure 7: Detailed Curve of the ratio σx/σy as a function of Φ(t)

The approximate equation for this trend is:

$$\frac{\sigma_x}{\sigma_y} \approx \frac{2.126}{\Phi^{0.969}} \tag{30}$$

The notable points here are: For Φ≈2.16, at the beginning of the process, the two variances are practically equal, and σx/σy≈1, given that the bias imposed by the advection shear effect is just beginning. For later events, when Φ≈0.38, the two values progressively diverges to infinity.For this reason, as a practical limit of the expansion of the function, it is taken no longer to 0.38. Note that this limit is the one of interest, since up to this point, the "Mixing Length" is obtained.

Therefore, the Gaussian ratio of the longitudinal and transverse transport coefficients will be:

$$\frac{\sigma_x}{\sigma_y} \approx \sqrt{\frac{E}{\varepsilon y}} \tag{31}$$

And therefore:

$$\frac{E}{\epsilon y} \approx \left(\frac{\sigma_x}{\sigma_y}\right)^2 \tag{32}$$

Normally the longitudinal coefficient, E, is known, then the transverse coefficient will be:

$$\boldsymbol{\varepsilon y} \approx \frac{E}{\left(\frac{\sigma_x}{\sigma_y}\right)^2} \tag{33}$$

This value of εy must be contrasted with the one calculated from the Elder corrected eq. (19), which is considered an acceptable standard for the channel under study.

V. Practical Application of the Method to Real Channels in Colombia and USA

a) Upper Guavio River, Colombia in 2001

For this study, we consider saline tracer (NaCl) experiments conducted by the Universidad de los Andes in Bogotá in 2001 on the upper Guavio River, a mountain , very roughness river near the town of Arbelaez in the center of the country. [28] Figure 8.



Source: Author

Figure 8: View of Rio Guavio, near Arbelaez. Colombia

The data of this stream experiment is in Table 1.

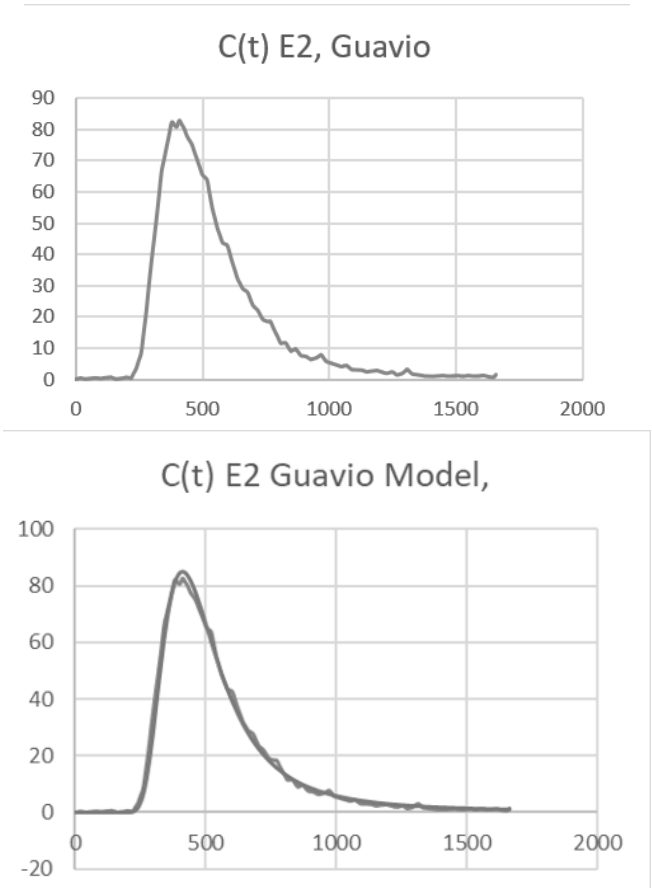
Table 1: Experimental data at Rio Guavio

Date: June 17, 2001. 2n station curve.
2ond curve length: X = 98.1 (m)
Width: W ≈ 10.0 (m)
Depth: H ≈ 0.25 (m)
Hydraulic radius: R≈0.22 (m)
Slope: S ≈ 0.045
Cross-sectional area: Ayz ≈ 2.3 (m2)
Roughness (Manning): n ≈ 0.32
Flow rate: Q ≈ 0.550 (m3/s)
Average velocity: U ≈ 0.24 (m/s)
Mass (NaCl): M ≈ 12233.0 (g)
Peak time: tp ≈ 410.0 (s)
State function: Φ ≈ 0.55
Longitudinal coefficient: E ≈ 0.77 (m2/s).

Source: Author

The experimental tracer curve and its model, using equation (9), for that experiment at the second station, are shown in Figure 9.

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Source: Author

Figure 9: Experimental curve (broken) and superimposed model (soft), using equation (10)

As can be seen at a distance of X1=98.1 (m) and with a State Function of $\Phi 1 \approx 0.55$, does not yet reach the condition of complete mixing, which occurs at $\Phi \approx 0.38$, then the unknown distance, Lo, must be estimated approximately with the eq. (7):

$$\frac{\Phi 1}{\Phi 2} \approx \frac{\sqrt{X2}}{\sqrt{X1}} \tag{34}$$

Then:

$$\sqrt{X2} \approx \sqrt{98.1} * \left(\frac{0.55}{0.38}\right) \approx 14.33 \tag{35}$$

So:

$$X2 \approx Lo' \approx 206.3\ (m) \tag{36}$$

Now, ratio σ_x/σ_y, eq. (30) is then calculated for $\Phi \approx 0.38$

$$\frac{\sigma_x}{\sigma_y} \approx \frac{2.126}{(0.38)^{0.969}} \approx 5.43 \tag{37}$$

And the transverse transport coefficient, εy, is as in eq. (33):

$$\varepsilon y \approx \frac{E}{\left(\frac{\sigma_x}{\sigma_y}\right)^2} \approx \frac{0.77}{5.43^2} \approx \frac{0.77}{29.5} \approx 0.026\ \left(\frac{m2}{s}\right) \tag{38}$$

This Coefficient is verified against the value obtained by Elder:

$$\varepsilon y \approx 0.6 * 0.25 * \sqrt{0.25 * 9.83 * 0.045} \approx 0.050\ \left(\frac{m2}{s}\right) \tag{39}$$

The ratio of the two results are 1.92, then, of the same order of magnitude, and are accepted as valid verification. The mixing length Lo, eq. (2), is then:

$$Lo \approx \frac{0.1 * 0.24 * 10^2}{0.026} \approx 92.3(m) \tag{40}$$

Comparing with Lo´ calculated with eq. (7) , it is noted that Lo´>Lo and it is accepted that With a central injection (k=0.1) the dispersion covers the width of the channel, but as Lo´ is greater, the solute does not yet have a homogeneous distribution in its volume. Although the transverse diffusion coefficient has been calculated with a good approximation to the reference (Elder-Fischer), since there is no strict control over the exact injection, the multiplier "k" may vary. In this case, the Lo´ figure can be considered more precise since it does not depend on this factor.

b) Rio Bogota, Colombia in 2024

The Bogota River near the flower farms in the capital is a small to medium-sized plain river with a gentle gradient. In this day were used fluorescent tracer (RWT). Figure 10.



Source: Author

Figure 10: Bogota River, near capital, in Colombia.

The river experimental data on that day were in Table 2.

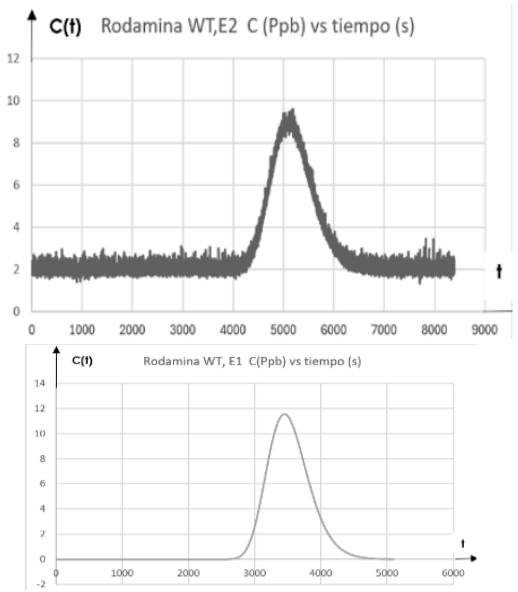
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Table 2: Experimental data at Rio Bogota

Date: September 5, 2024. 2ond station curve
2ond curve length: X = 3515.0 (m)
Width: W ≈ 20.0 (m)
Depth: H ≈ 2.3 (m)
Hydraulic radius: R≈1.58 (m)
Slope: S ≈ 0.0006
Cross-sectional area: Ayz ≈ 38.8 (m2)
Roughness (Manning): n ≈ 0.025
Flow rate: Q ≈ 26.8 (m3/s)
Average velocity: U ≈ 0.69 (m/s)
Mass (RWT): M ≈ 160.0 (g)
Peak time Second curve: tp ≈ 5097.0 (s)
State function: Φ ≈ 0.167
Longitudinal coefficient: E ≈ 7.25 (m2/s).

Source: Author

The experimental tracer curve and its model, eq. (10), for that experiment at the second station, are shown in Figure 11.



Source: Author

Figure 11: Experimental curve (red) and superimposed model (gray)

As can be seen, the "Complete Mixing" condition for Dispersion was reached at an earlier point, since Φ<0.38, therefore equation (7) must be applied to calculate approximately the distance X1 at which it occurred with $\Phi_1 \approx 0.38$:

$$\sqrt{X1} \approx \left(\frac{\Phi 2}{\Phi 1}\right) * \sqrt{X2} \qquad (41)$$

And then:

$$\sqrt{X1} \approx \left(\frac{0.167}{0.38}\right) * \sqrt{3515} \approx 26.1\ (m^{\frac{1}{2}}) \qquad (42)$$

And therefore, X1≈Lo´≈681.0 (m)
Now, eq. (30) is then calculated for Φ≈0.38:

$$\frac{\sigma_x}{\sigma_y} \approx \frac{2.126}{(0.38)^{0.969}} \approx 5.43 \qquad (43)$$

And the transverse transport coefficient, εy, is in eq. (33):

$$\varepsilon y \approx \frac{E}{\left(\frac{\sigma_x}{\sigma_y}\right)^2} \approx \frac{7.26}{5.43^2} \approx \frac{7.26}{29.5} \approx 0.25\ \left(\frac{m2}{s}\right) \qquad (44)$$

It is verified against the value obtained by Elder-Fischer:

$$\varepsilon y \approx 0.6 * 2.3 * \sqrt{2.3 * 9.83 * 0.0006} \approx 0.160\ \left(\frac{m2}{s}\right) \qquad (45)$$

The ratio of the two results are 1.56, then, of the same order of magnitude, and are accepted as valid verification.

$$Lo \approx \frac{0.1 * 0.69 * 20^2}{0.25} \approx 662.4\ (m) \qquad (46)$$

Comparing with Lo´, calculated with equation (7), it is noted that Lo´≈ Lo (same order) and it is accepted that the calculation on the width of the channel is equivalent to the criterion of homogeneous distribution of the tracer on the solute current tube.

c) Caltech Channel, USA in 1966

A third example is documented, a tracer experiment carried out by H. B. Fischer [29] on the 40 (m) calibrated channel of the W. M. Keck Laboratory at Caltech, in 1966. In this experiment (Series 2700), Fischer injected NaCl as a tracer, measuring two sequential curves. The objective of the experiment was to test Elder's diffusion theory. Figure 12.



Source : [3]

Figure 12: W.M. Keck 40 (m) channel in Caltech. USA

The channel experimental data on that day were in Table 3:

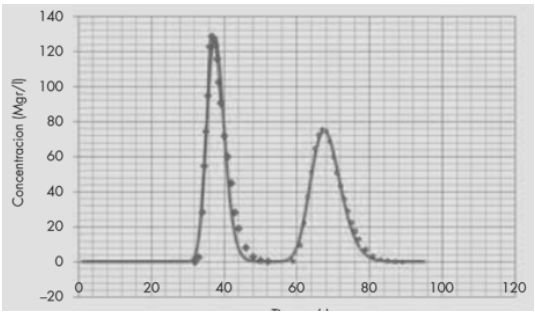
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Table 3: Experimental data at Caltech channel

Date: 1966. 2ond station curve.
2nd curve length: X = 25.06 (m)
Width: W ≈ 1.09 (m)
Depth: H ≈ 0.128 (m)
Hydraulic radius: R≈0.104 (m)
Slope: S ≈ 0.0002
Cross-sectional area: Ayz ≈ 0.14 (m2)
Roughness (Manning): n ≈ 0.009
Flow rate: Q ≈ 0.053 (m3/s)
Average velocity: U ≈ 0.372 (m/s)
Mass (NaCl): M ≈ 40.5 (g)
Peak time 2ond curve: tp ≈ 67.4 (s)
State function 2ond curve: Φ ≈ 0.130
Longitudinal coefficient: E ≈ 0.0169 (m2/s).

Source: Author

The experimental (dotted lines) two tracer curves and the models (thick continuous lines), are shown in Figure 13.



Source: Author

Figure 13: Experimental curves (dotted) and superimposed model (thick continuous line)

As can be seen, the "Complete Mixing" condition for Dispersion was reached at an earlier point, since Φ<0.38, therefore eq. (7) must be applied to calculate approximately the distance at which it occurred, with X2≈25.06 (m), and Φ2≈0.130. It is necessary that Φ1≈0.38 as explained.

$$\sqrt{X1} \approx \left(\frac{\Phi 2}{\Phi 1}\right) * \sqrt{X2} \tag{47}$$

And then:

$$\sqrt{X1} \approx \left(\frac{0.130}{0.38}\right) * \sqrt{25.06} \approx 1.71\ (m^{\frac{1}{2}}) \tag{48}$$

And therefore, X1≈Lo´ ≈ 2.93 (m)
Now, eq. (30) is then calculated for Φ≈0.38

$$\frac{\sigma_x}{\sigma_y} \approx \frac{2.126}{(0.38)^{0.969}} \approx 5.43 \tag{49}$$

And the transverse transport coefficient, εy, is in eq. (33):

$$\varepsilon y \approx \frac{E}{\left(\frac{\sigma_x}{\sigma_y}\right)^2} \approx \frac{0.0169}{5.43^2} \approx \frac{0.0169}{29.5} \approx 0.0006\ (\frac{m2}{s}) \tag{50}$$

It is verified against the value obtained by Elder:

$$\varepsilon y \approx 0.6 * 0.128 * \sqrt{0.128 * 9.83 * 0.0002} \approx 0.00122\ (\frac{m2}{s}) \tag{51}$$

The ratio of the two results are 4.92, not so convergent to unit, but of the same order of magnitude, and are accepted as valid verification.

The mixing length Lo, eq. (2), is:

$$Lo \approx \frac{0.1*0.372*1.09^2}{0.0006} \approx 73.7\ (m) \tag{52}$$

The two notable distances, Lo and Lo', differ greatly in their values, indicating that longitudinal dispersion achieves the mixing effect first, rather than transverse diffusion, which has an exaggeratedly high value for the special scope of the channel, indicating that probably in artificial channels, with very small Longitudinal transport coefficient, the indicated method to establish "Complete Mix" is the Lo´ calculation.

VI. Results and Discussions

1. This article develops criteria to estimate when a flow reaches the "Complete Mixing" condition. When using the classic Rutherford formula, the transverse diffusion coefficient is calculated from the ratio of longitudinal and transverse variances, using a nonlinear distribution function of Φ, and the value of the longitudinal dispersion coefficient. The values of these calculations are convergent with those found by the Elder-Fischer formula. The alternative criterion is based on finding the distance from the tracer at which Φ ≈ 0.38, and the solute is considered homogeneously distributed in the volume covered by the tracer.
2. The first criterion estimates that the tracer fills the channel width, while the second does not.
3. In real streams, the two criteria can sometimes converge, and sometimes not. In very large rivers (with very large widths), where the "mixing lengths" calculated using the classic formula are very long, the other criterion should be preferred, since the interest is often to determine the advection-dispersion characteristics at a certain intermediate point (not across the entire width).
4. To characterize the evolution of the conservative solute in the flow, a state function Φ, is documented, which describes the different notable moments analyzed here.
5. To verify whether this value of εy is consistent with Elder's classic calculation, taken as a reference, the method is applied to a real field experiment.

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Appraisal of Covid-19 on Forest Resources and Extension Approaches Towards Sustainable Rural Livelihood

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Abstract- The people's livelihood is largely dependent upon forests and related resources which comprises the tangible and intangible ones. Tangible resourcesare in the form of Timber, Non-Timber Forest Products (NTFPs) such as mushroom, fruits etc. while intangible services include a wide range of vital environmental services by the floras and faunas which includes erosion control, carbon sequestration among others. Assessing these tangible resources was always through active physical involvements by the actors in the management of the forests. Unexpectedly, the outbreak of COVID-19 pandemic which was earlier endemic to China have created a barrier to man in the management and utilization of these forest resources. Imposed lockdowns, curfews, social distances meant less team work, access and utilization of forest resources globally. The unavoidable reliance on forest resources especially by rural dwellers in developing nations like Nigeria was observed to spike up.

Keywords: *extension services, NTFP, COVID 19, pandemic and sustainability.*

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Appraisal of Covid-19 on Forest Resources and Extension Approaches Towards Sustainable Rural Livelihood

Salami, K. D. [α], Bashir, M. G. [σ] & Nasir, T. Y. [ρ]

Abstract- The people's livelihood is largely dependent upon forests and related resources which comprises the tangible and intangible ones. Tangible resourcesare in the form of Timber, Non-Timber Forest Products (NTFPs) such as mushroom, fruits etc. while intangible services include a wide range of vital environmental services by the floras and faunas which includes erosion control, carbon sequestration among others. Assessing these tangible resources was always through active physical involvements by the actors in the management of the forests. Unexpectedly, the outbreak of COVID-19 pandemic which was earlier endemic to China have created a barrier to man in the management and utilization of these forest resources. Imposed lockdowns, curfews, social distances meant less team work, access and utilization of forest resources globally. The unavoidable reliance on forest resources especially by rural dwellers in developing nations like Nigeria was observed to spike up. Thus, further depleting the encroached forest resources while in the west forest restorations were reported. Comparative results revealed issues of poverty, food insecurity and lack of information as the factors in Nigeria. Extension models for sustainability of forest resources was advanced.

Keywords: extension services, NTFP, COVID 19, pandemic and sustainability.

I. Introduction

a) Pandemic and Covid 19 Coronavirus Disease-2019

Forests provide clean water, air, timber for wood products, wildlife habitats, stable soil, and recreational opportunities, and beautifies the environment. Furthermore, they also are important economic resources producing marketable timber and non-timber resources like fruits and fiber. By virtue of their importance as territories, forests are integral to conserving biological diversity and the ecosystems and also provides sources of livelihoods (UNEP, 2001; Agrawala *et al.,* 2003; Magreth and peter, 2016). Sustainable consumption refers to the use of products, materials, and energy according to sustainable development principles. The conservation of natural resources and energy ensures that minimal impact on environment occurs through man's activities. It also entails minimizing the use of toxic substances and materials for production. Amidst the struggle to entrenched sustainable utilization of resources and improve food security, especially in developing countries like Nigeria the COVID-19 Pandemic hit the world. Subsequently, a new normal entails minimal contact through social distancing and even lockdown. This affects livelihoods of African population that are usually '*daily food hunters*'that do not have reserve of food. Thus, the pandemic changed everything and caused a break in the food value system and the overall livelihood of especially the populace. Importantly, it was observed that the felling of trees for firewood increased within the lockdown period. Reconnaiss ancesurvey revealed that for traders that could no longer engage in their usual marketing and travelling practices engaged in felling off trees for sell as firewood within rural communities where the lockdown was not as seriously enforced.

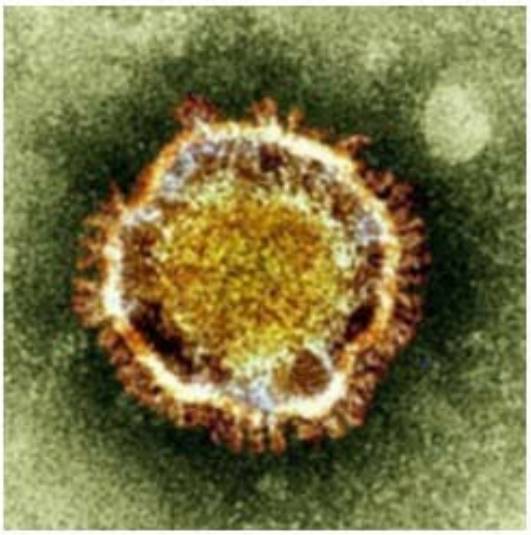
Pandemics are hazards related to large-scale outbreaks of infectious diseases that can greatly increase morbidity and mortality over a wide geographic area and cause significant economic, social, and political disruption (Madhav *et al.,* 2017). The consequences of a pandemic, affecting people on a worldwide scale, with expected long-term impacts and consequences on the coupled socio-ecological system, can be described as a disaster. The wide-spread of coronavirus (Covid-19) was confirmed on the 27 February, 2020 in Lagos, Nigeria's commercial capital with a population of 21 million. The COVID-19 that started out as an epidemic in Wuhan, China in December 2019 and ended up as a pandemic (affecting the whole world) has thrown the world into a war-like situation. Many cases of deaths have been recorded cumulatively for all countries from across the world.

The Coronavirus Disease-2019 (COVID-19) is caused by a novel Coronavirus, called the Severe Acute Respiratory Syndrome Coronavirus-2 (SARS-CoV-2). It is an enveloped non-segmented positive sense single-stranded RNA virus in the family *Coronaviridae.* In appearance, the virus looks like a crown under the electron microscope (Figure 1), hence the name, "Corona". Like other coronaviruses, the COVID-19 virus genome is about 400-500nm in size and encodes

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structural proteins (e.g spike glycoprotein and accessory proteins), as well as non-structural proteins such as RNA dependent RNA polymerase, helicase, papain-like protease and 3 chymotrypsin-like protease. The virus is believed to be more infectious than its counterparts: SARS and MERS (Enitan *et al.,* 2020; Ibeh *et al.,* 2020; Guamer, 2020).



Credit: Pasieka/Science Photo Library

Figure 1: Coronavirus as seen under the electron microscope

As of May 16, 2020, the COVID-19 virus has spread to 188 countries and territories, with 4,614,135 total confirmed cases and 310,520 total deaths globally (JHU-CSSE, 2020). The top 14 most hit countries as indicated by Johns Hopkins University Center for Systems Science and Engineering are: US (1,463,350), Russia (272,043), United Kingdom (241,455), Spain (230,698), Italy (224,760), Brazil (222,877), France (179,630), Germany (175,752), Turkey (148,067), Iran (118,392), India (90,648), Peru (88,541) and China (84,038) and Canada (77,082).

It is evident that there was really no preparation to arrest the earliest cases of importation of Covid-19 into the country which could have been done at the points of entry into the country, especially at the international airports. Effective quarantine of travelers coming into the country, since the Chinese outbreak became news in January could have been done. It was not until much later, by 18 March 2020, that Nigeria eventually placed a travel ban on 13 countries with high incidence of the disease namely the United States, United Kingdom, South Korea, Switzerland, Germany, France, Italy, China, Spain, Netherlands, Norway, Japan and Iran. It was later that the banof all international flights into and out of Nigeria took effect on 23 March 2020. This uncoordinated approach came rather late as many returnees had already melted into the communities.

A number of the measures adopted to contain the virus in the country embrace restriction of movements, airports and land borders closure, patients transfer and isolation, diagnosis, tracing and follow-up of potential contacts, sustaining scaling of laboratories, upgrading and creation of treatment centers and public health funding, provision of palliatives to the vulnerable population, etcetera. However, the above measures are constrained by poor health care infrastructure and alternative COVID-19 pre-existing fragilities like poverty weak institutional framework, and falling oil costs.

Corona Virus Disease (COVID-19) pandemic has hit all sectors of economy, where the impact was projected tobe quite immense in the agriculture, industry, tourism, and remittances (ADB 2020(FAO, 2020). This means there is need for serious sensitization on the Pandemic as well as on the importance of forest products for a sustainable ecosystem. The understanding of people's dependence on forest products can assist and support the activities of conservation and development policy interventions as sustainable forest management (McShane and Wells, 2004). On the other hand, recent literature highlighted the positive side of the COVID-19 or lockdown, such as strict quarantine benefits environment (Wang and Su, 2020) or ecosystems are being greatly recovered (Chakraborty and Maiti, 2020).

To attain this objective, the paper is split into 5 sections. Section one is the introduction. Section 2impact of COVID 19 on forest and Ecosystem, Section 3 highlights the means through which forest products can mitigate COVID-19 and sustain livelihood; section 4 to enumerate the impact of extension services on COVID-19 and to recommend policies for sustainability of biodiversity. This paper is a review of the impact of the non-timber forest product and extension services as

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means of mitigating the effect of COVID 19 pandemic for sustainability.

i. *Non-Timber Forest Product as a Forest Resource*

Non-Timber Forest Products (NTFPs) are useful substances, materials or commodity obtained from forest that do not require the harvesting of trees (Saka, *et al.,* 2020; FAO, 2018, FOSA, 2001). The term Non-Timber Forest Products (NTFPs) emerged as an umbrella to recognize the products derived from various forest resources as a group. Non-timber forest products are plants and /or forest products that are valued for other purposes beside timber. They have been described as all biological materials of plant and animal origin other than wood that are extracted from the forest for human use and are mainly technological processing (Ibrahim *et al.,* 2016). It comprises such diverse product as game, starchy foods, nut, spices, leaves, for wrapping food, medicinal herbs, essentials oils, latex for rubber and rattan (Ros-Tonen, 1999). Although some authors (Sizer, 1996) tend to include ecotourism among NTFPs.

The COVID-19 pandemic has underscored the significance of Non-Timber Forest Products (NTFPs) in African countries, where they are widely used as food, medicine, and a source of income for local communities. The use of NTFPs, particularly medicinal plants, has been reported to be on the rise during the pandemic, with many believing they can drive away flu-related ailments and boost immunity. In Kenya, Uganda, and Tanzania, for instance, stakeholders, including local community representatives, reported an increased interest in NTFPs, with trees and shrubs with medicinal values gaining popularity on social media. The Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) estimates that 75% of approved antimicrobial drugs are derived from natural or naturally derived compounds, highlighting the importance of NTFPs in primary health care services, particularly in remote rural areas. However, the lack of data and information on NTFPs, despite their increasing demand and use, poses a significant challenge to understanding their contribution to livelihoods and economies. Furthermore, the effectiveness of NTFPs in treating diseases is often not scientifically established, providing an opportunity for future research to gather evidence on their efficacy. Overall, the COVID-19 pandemic has brought to the fore the need to develop methodologies to document the contribution of NTFPs to livelihoods and economies, and to conduct research on their effectiveness in treating diseases, in order to promote their sustainable use and conservation.

ii. *NTFPS: A Means to Sustainable Rural Livelihoods*

The need to promote sustainable development of non-timber forest products in Nigeria has become imperative. While these set of resources have contributed to income generation and livelihood in rural economies, their roles as a foreign exchange earner and as raw materials in the nation's industrial sector are yet to be reaped to full potentials.

Alongside stabilizing ecosystem, resuscitating the environment one other virtue of the NTFP resources is the potentials it holds in sustaining rural livelihoods. The rural dwellers are most often poor, impoverished and marginalized where the basics amenities like health care are not provided.

In this regard, (Saka *et al.,* 2019) posited that NTFPs extends opportunities for the people of Gujba LGA in Yobe State Nigeria through providing fruits, gums and wildlife for income generation. For the poor rural dwellers, the main source of energy is firewood and charcoal. This means continued exploitation of the forest resources. Other sources of income and of great importance to NTFPs sustainability are the bees that provides honey and beeswax. They also are the major vectors of pollination of the plants thus responsible for the sustenance of biodiversity and development (Hertz, 2002; Reinhard and Admasu, 1994).

Honey and beeswax are two important NTFP that are major sources of nectar and pollen. Examples of trees that provide good nectar/pollen in Nigeria include *Anacadium occidentale*, *Citrus spp*, *Cocus nucifera, Mangifera indica and Talinium triangulare*. Bees are responsible for the pollination of many flavouring plants and are therefore important in sustaining biodiversity (Hertz, 2002). According to beekeeping has significant role in forest conservation and development.

NTFP plants employed as food products include wild fruits, vegetables, nuts, edible roots, bush meat, edible insects, honey, oil, saps and food additives such as spices, flavourings, food colourants and fermentation agents. Okafor (1975) classified the dietary importance and consumption of NTFP's into five.These include those taken as main food such as *Treculia africana*, food supplements such as *Dacryodes edulis*; condiments such as *Irvingia gabonensis, Mucuna sloana, Parkia clappertoniona* and *Prosopis africana*; and leafy vegetables such as *Vitex doniana.* Berries, herbs and mushrooms are among the most valuable of NTFP plants being harvested and sold to established markets across the globe (Barfoot, 2006).

A number of NTFP are used as fodders for grazing animals. Examples of these are species such as *Asystacia gigantica, Gossandra nilotica, Commiphora africana, Bombax buonopozense, B. costatum, Tecoma capensis, Combretum aculeatum and Polycarpaea corymbosa.* (Jimoh, 2005). Likewise, Shea butter, is now becoming one of the best-selling and highly recommended beauty skin products. It generatedUS$61 million in 2004. While these can be considered right steps in the right direction, the processing of these products locally before their and exportation will generate far higher foreign exchange in addition to providing employment locally.

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Table 1: List of Non-Wood Forest Products removals and value of removals

SN	Plant products	Animal Products
1.	Food	Living animals
2.	Fodder	Hides, skin and trophies
3.	Raw material for medicine and aromatic products	Wild honey and bee-wax
4.	Raw materials for colorants and dyes	Wild meat
5.	Raw materials for utensil, handicraft and construction	Raw material for medicine
6.	Ornamental plants	Wild meat
7.	Exudates	Raw materials for colorants
8.		Raw material for medicine
9.		Other edible animal products
10.		Other edible non animal products

Adapted from FAO (1991); FRA (2010)

Table 2: Forest Region by Area

Region / Subregion	Forst area(1000ha)			
	1990	2000	2010	2020
Eastern and southern Africa	346034	322580	314849	295778
Northern Africa	39926	38104	36833	35151
Western and central Africa	356842	339365	324333	305710
Total Africa	**742801**	**710049**	**676015**	**636639**
East Asia	29906	229071	252390	271403
South and southeast Asia	326511	308077	305461	296047
Western and central Asia	48976	50262	53109	55237
Total Asia	**585393**	**587410**	**610960**	**622687**
Europe excl. Russian federation	185369	193000	198847	202150
Total Europe	994319	1002268	1013982	1017461
Caribbean	5961	6808	7497	7889
Central America	28002	25819	33706	22404
North America	721317	719721	722987	722417
Total north and central America	755279	752349	754190	752710
Total Oceania	184974	183328	181015	185248
Total South America	973666	922645	870154	844186
World	4236433	4158050	4106137	4058931

Source: United Nations, 2021; FAO, 2020

Table 3: Rate of Forest Loss

Region /Subregion	1990-2000		2000 - 2010		2010-2020	
	1000hayr^{-1}	%	1000hayr^{-1}	%	1000hayr^{-1}	%
Eastern and southern Africa	-1345	-0.40	-1773	-0.55	-1907	-062
Northern Africa	-182	-0.47	-127	-0.34	-168	-0.47
Western and central Africa	-1748	-0.50	-1503	-0.45	-1862	-0.59
Total Africa	*-3275*	*-0.45*	*-3403*	*-0.49*	*-3938*	*-0.60*
East Asia	1917	0.88	2332	0.97	1901	0.73
South and southeast Asia	-1843	-0.58	-262	-0.09	-941	-0.31
Western and central Asia	129	0.26	285	0.55	213	0.39
Total Asia	*202*	*0.03*	*2355*	*0.39*	*1173*	*0.19*
Europe excl. Russian federation	763	0.40	585	0.30	330	0.16

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Total Europe	*795*	*0.08*	*1171*	*0.12*	*348*	*0.03*
Caribbean	85	1.34	69	0.97	39	0.51
Central America	-218	-0.81	-211	-0.85	-130	-0.56
North America	-160	-0.02	327	0.05	-57	-0.01
Total north and central America	*-193*	*-0.04*	*184*	*0.02*	*-148*	*-0.02*
Total Oceania	*-165*	*-0.09*	*-231*	*-0.13*	*423*	*0.23*
Total south America	*-5102*	*-0.54*	*-5249*	*-0.58*	*-2597*	*-0.30*
World	*-7838*	*-0.19*	*-5173*	*-0.13*	*-4739*	*-0.12*

Trends in forest area (1990 -2020) and net annual change in forest cover for the different regions in Africa as shown in Table 2 reflect a decline in the forest areas in the region between 1990 and 2020. However, trends in forest cover are usually over longer time frames and the full impact of COVID-19 on forest areas of Africa may take a longer period to be experienced.

Source:United Nations, 2021; FAO, 2020

iii. *Militating Factors Against NTFPS Sustainable Development*

Despite their wide applications, a number of problems are militating against optimal development and utilization of NTFP plants in Nigeria. These have made it difficult to obtain adequate benefits from their harvesting and sales locally and on global basis. Some of the major constraints are subsequently discussed. Among the problems militating against the sustainable development of the resources are neglect by policy makers, planners and forest managers, lack of detailed inventory on NTFP plants which makes categorization and send use classification difficult. The methods of harvesting, overgrazing and overdependence on them by local communities also constitute major problems militating against the use of the resources.

The current local and global policy initiatives most especially, the need to achieve Millennium Development Goals of poverty alleviation, extreme hunger, women empowerment, quest for permanent cure for HIV/ AIDS, malaria coupled with increased local drive for foreign exchange earnings from green sources in the face of increasing climate change problems associated with power generation from crude oil and development of improved technology are likely to drive the sustainability of NTFP plants in Nigeria.

Other factors that limit the potential of NTFPs to forest dwellers incomes are related to marketing problems. Among these are lack of information on potential markets and marketing channels, fragmentated nature of NTFP markets, the lack of sufficient volume and the unpredictability of the production cycle, resulting in irregular supplies (Panayotou, 1991). The perishable nature of many products combined with the poor infrastructure and high transportation cost in the tropical rainforest areas also hinder the successful marketing of NTFPs, together with the lack of organization among harvesters and lack of access to credit and storage facilities (Verhey and Reinder, 1997).

In general, the potential contribution of commercial NTFP exploitation to improved livelihoods for forest dwelling people is limited for NTFPs from natural forests, because of the low densities at which they occur and their irregular distribution (Van Dijk, 1999). Also, the sum of marketing of NTFPs from natural cannot simply be expected to function as a vehicle for improved livelihoods. It is inherent in NTFP-based livelihoods that they tend to disappear.

b) Challenges and Opportunities for Sustainable Rural Livelihoods

The COVID-19 pandemic has brought unprecedented challenges to forest resource management and rural livelihoods worldwide. Studies have shown that the pandemic has accelerated deforestation and forest degradation, particularly in tropical regions, due to increased demand for land, timber, and non-timber forest products (NTFPs) (WWF, 2020). The closure of national parks and protected areas during lockdowns has also led to an increase in poaching and wildlife trafficking, further threatening biodiversity (IUCN, 2020). Moreover, the pandemic has disrupted global supply chains, affecting the livelihoods of forest-dependent communities, particularly those relying on NTFPs, such as medicinal plants, fruits, and nuts (Kusters et al., 2020). However, the pandemic has also created opportunities for sustainable forest management and rural livelihoods. For instance, the shift towards online platforms and digital technologies has enabled forest-dependent communities to access new markets and customers, increasing their income and livelihood resilience (FAO, 2020). Additionally, the pandemic has highlighted the importance of sustainable forest management and conservation for human well-being, particularly in terms of providing ecosystem services, such as clean air and water, and regulating climate change (IPBES, 2020). Therefore, it is essential to adopt innovative and inclusive approaches to forest resource management, such as community-led forest management, agroforestry, and sustainable forest certification, to promote sustainable rural livelihoods and conserve forest ecosystems for future generations (Chomba et al., 2020; Sunderland et al., 2020). Overall, the COVID-19 pandemic has underscored the need for a more sustainable and equitable approach to forest resource management, one that balances human well-being with environmental conservation and promotes resilient rural livelihoods.

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c) *Impact of Covid-19 on Forests and Ecosystem Around the World*

The COVID-19 pandemic has severely impacted Africa's forest sector, affecting forest management, conservation, and livelihoods. Movement restrictions and social distancing measures have led to reduced revenues, decreased funding, and increased deforestation and illegal harvesting of timber and non-timber forest products. The pandemic has also disrupted conservation efforts, leading to increased poaching and illegal trade in endangered species. The economic impacts have been significant, with declines in production, international trade, and investment in the forest sector. Furthermore, the pandemic has highlighted the importance of non-timber forest products, such as medicinal plants, which have seen increased demand. Generally, the pandemic has exacerbated existing challenges in Africa's forest sector, emphasizing the need for sustainable forest management and conservation practices to ensure the long-term health of Africa's forests and the livelihoods of forest-dependent communities(United Nations, 2021).

The instability caused by the pandemic is characterized by variables that have sudden and multiple impacts on both the natural environment and on society and could push thesystem into three different potential states. Furthermore, one of the more striking ecological consequences of the COVID-19 pandemic that has swept the world was the response of wildlife to the sudden absence of humanity. From a popular media perspective, habitat all around us was seemingly restored overnight (Wright, 2020). News reports in early 2020 were filled with images of wildlife in unorthodox settings: wild boar foraging in the center of Barcelona, Spain; nesting sea turtles on deserted sunbathing beaches in Brazil; and even a typically nocturnal small Indian civet filmed in broad daylight on a crosswalk in Kerala, India. There have also been dramatic environmental changes—for example, a marked and sustained reduction in global anthropogenic seismic noise (Lecocq *et al.,* 2020), and improved air quality and reduced NO_2 levels, with clearer skies above many major cities (NASA, 2020). Forest landscape fragmentation also may facilitate human contact with wild animals, increasing the likelihood of transmission risk of animal-to-human viruses (Weerasinghe, 2018; Barrett and Bouley, 2015).

A study released during the COVID-19 pandemic estimates that spending of USD 260 billion per year over ten years on measures such as combating deforestation, improving management of global wildlife trade, ending the wild meat trade in China and improving disease surveillance in wild and domestic animals, would substantially reduce the risk of another pandemic. This investment is equivalent to 2% of the authors' estimated cost of the COVID-19 pandemic Dobson (2020).

Land-use change and wildlife exploitation (capture, hunting and trade) increase disease risk by bringing people and domestic animal populations in close proximity to pathogen-carrying wildlife. Human pressure on ecosystems can also alter infectious disease dynamics by disrupting the species composition, Function and structure of ecosystems (Karesh *et al.,* 2012); Keesing *et al*., (2010); Halliday and Rohr, 2019)(Table 1 and 3). For example, when an ecosystem is disturbed its species diversity may decline while the abundance of "generalist" or "opportunistic" species increases. The pandemic has also had an impact on ecological research, field work and experiments. In many cases, this research activity has been diminished or halted, with important consequences on conservation of species and habitats.

During the COVID-19 epidemic, there is a misconception that nature is "getting a break" from people. Instead, illegal mining, deforestation, wildlife poaching, and land grabbing are putting more strain on many tropical rural regions. People who lost their jobs in the metropolis are going back to their rural homes, which puts more strain on natural resources and raises the possibility that COVID-19 will spread to rural areas. Increased deforestation has been reported in Latin America, Africa, and Asia in the meantime. Remote indigenous groups may be exposed to the virus as a result of illegal miners and loggers encroaching on their lands. Because tourism has stopped, areas that rely on it for their economic survival have fewer resources, which has led to an increase in the eating of bushmeat, or wild meat. There is also a possible economic impact on conservation programs around the globe as a result of pandemic and different programs are assessing their long-term viability (such as the Global Environmental Fund) (OECD, 2020). Even after the pandemic ends, a danger exist that both research and conservation programs will be diminished mainly due to miscommunication between decision makers and scientists. However, perhaps the most important impact of the pandemic on the ecological transition focuses on sustainability and the still possible choices that the society could make to ensure its long-term survivability.

The world is facing its sixth mass extinction event, with one million plant and animal species now threatened with extinction due to changes in land and sea-use, overexploitation, climate change, pollution and invasive alien species (Diaz *et al.*, 2019). Since 1970, populations of mammals, birds, reptiles, amphibians and fish have declined on average by 68% and vast areas of ecosystems have been degraded (WWF, 2020). Human destruction of biodiversity is one of the leading drivers of infectious disease outbreaks (Loh, 2015). It also poses a significant risk to supply chains, businesses and the global economy. Investing in activities that protect and restore biodiversity would provide immediate jobs, while also reducing the risk of

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future crises and improving the resilience and long-term viability of businesses and the economy.

Potential workforce shortage in this period could impact the forest cycle activities (management, planting, harvesting) and reflect along the value chain. Current evidence does not necessarily predict a workforce deficit; however, the arrival of foreign workforce could be disturbed by applied travel restrictions. Some activities where potential workforce shortage could present a challenge are for example tree planting, which is around the corner in the Nordic countries, cork extraction in Southern Europe taking place from June to August and treatment of forest calamities. Some countries are exploring how to replace the potential lack of foreign workforce with a domestic one.

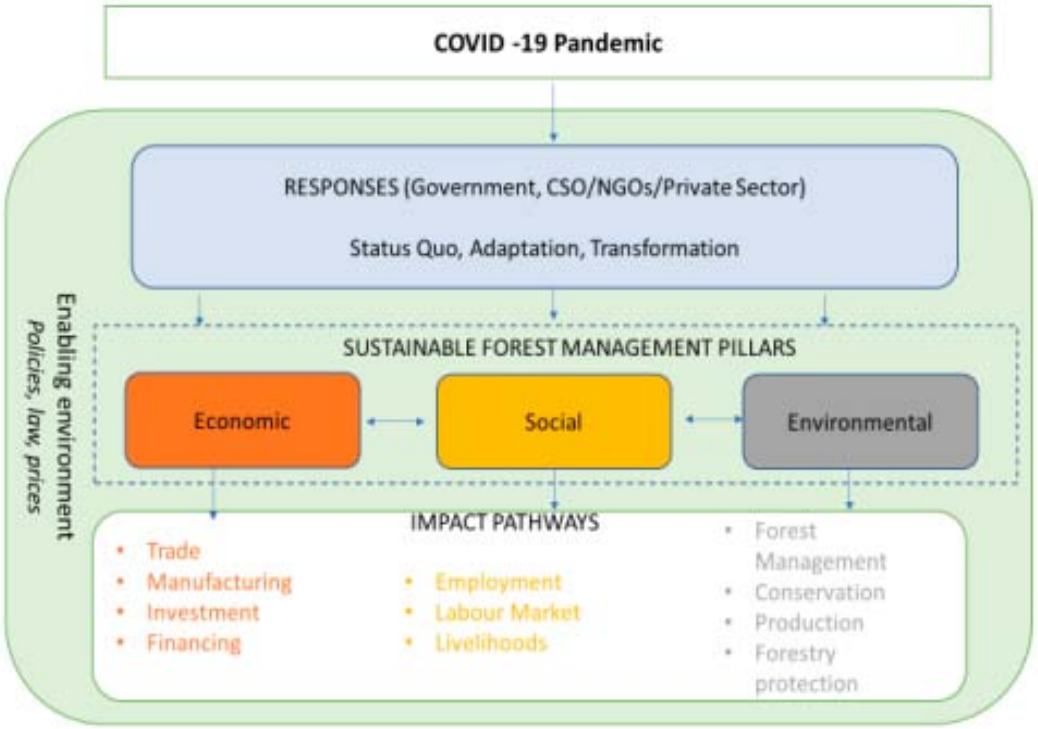
Covid-19's impact on forest-based industries will have immediate consequences for the forest owners, arising primarily from the continued decline in wood runoff and sales, mainly due to currently interrupted wood supply chain. Prices and volumes are linked to the general situation, which in the industry sector, shows different intensity, depending on the sector. Generally speaking, if the packaging, wood pallets (retail) and pulp for tissue and toilet paper see stability or some increase, others such as graphic paper, wood energy, construction, furniture and panel see a decrease in activities. As a result, sawmills have been largely impacted and some forest-based enterprises adapted their production chain to produce fibre protective material for sanitary use.

Table 4: Projected Impacts of COVID 19 on Tropical Forest Recovery and Restoration

	Predicted impact
	Ephemeral expansion of species ranges in natural and urban settings
Immediate and shorter term consequence	Increased gene flow and colonization events across normally fragmented anthropogenic landscapes through zoonotic disease transmission.
	Increased pressure on forest resource, including deforestation
	Reduction in sources populations of some species due to spike in illegal harvest.
	Reduction in group and volunteer restoration efforts (tree planting events)
	Reduction in site maintenance and monitoring of restored sites
	Lost opportunities for field research and training and disseminating results at national and international meetings
	Fewer opportunities for international collaborations
	UN CBD 2020 and UN COP 26 postponed
Long term consequences	Loss of restoration funding from ecotourism and funding from non –profits and private donors
	Suspended payments for ecosystem services
	Reduced restoration through voluntary carbon offsets (e.g airline)
	Strain on native plant supplier due to reduced demand
	Variable indirect impacts of economic shock (e.g loss of remittance, internal migration in developing nations to the country side, decreased research funding) Increase in interest in less expensive and more accessible protected areas due to increased poverty Reduction in wildlife trade due to lower demand and increase in illegal restrictions for species and habitat protection

Adopted Rakan etal., (2020)

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Source: United Nations, 2021

Figure 1: Assessment Frame

i. *Practical Approaches to other Impacts of Covid-19 on the Forest Sector*

a. Carry out an analysis of the impact of COVID 19 on various forest products markets and responses to the pandemic by regions.
b. Provide policy guidance to promote approaches to developing and transitioning towards a sustainable bio-economy, and meeting the climate goals of the Paris Agreement taking into account low prices for fossil resources and fossil resource-based materials.
c. In collaboration with the Advisory Committee on Sustainable Forest-based Industries and other related stakeholders identify effective, innovative responses to the impacts that COVID-19 might have on global forest-based industries in the short, medium and long term.
d. Maximize the use of available forest data as part of ongoing efforts to identify risks to loscal wild food sources and opportunities for developing local supply chains based on forest products.

ii. *Minimize the Impact on Global Trade and Supply Chains of Forest Products*

a. Strengthen national and regional markets for forest products, in order to maintain access to legally harvested wood and technology (technical assistance, training, equipment), and create channels of commercialization.
b. Coordinate strategies with ministries of economy, industry and trade to deliver targeted programmes based on public-private partnerships.
c. Maintain demand for legal timber and work with governments to enforce internationally agreed regulations on legally harvested timber. This is critical to enable timber-producing countries to implement national legislation that promotes sustainable forest management.
d. Amid disrupted international markets, boost the interest of governments and private sector actors in legal domestic timber production and processing, by providing more opportunities forsmallholders and other local timber producers.
e. Formalize and facilitate domestic timber production to supply local export-oriented industries. Over the years, these industries have increasingly relied on lower risk and better documented timber supplies imported from developed countries (with a high carbon footprint).

iii. *Present and Post- Mitigation of Covid-19 and Other Pandemics for Better Biodiversity*

1. Biodiversity attracts current and future human health, well-being and economic prosperity. Still, it is being destroyed at an unprecedented and accelerating rate, with 25% of all plant and animal species now threatened with extinction. It is

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therefore critical that countries integrate biodiversity considerations into their COVID-19 response and economic recovery plans.

2. Protecting biodiversity is important for avoiding the next pandemic. Close to three-quarters of emerging infectious diseases in humans come from other animals. Land-use change and wildlife exploitation increase infectious disease risk by bringing people and domestic animals in close proximity to pathogen-carrying wildlife, and by disrupting the ecological processes that keep diseases in check.
3. The economy and human well-being also depend on biodiversity for food, clean water, flood protection, erosion control, inspiration for innovation and much more. Over half the world's global domestic product is moderately or highly dependent on biodiversity. The ongoing decline of biodiversity therefore poses important risks to society. Investing in biodiversity as part of the COVID-19 policy response can help to minimize these risks, while providing immediate jobs and economic stimulus.
4. While government and business leaders have acknowledged the importance of a "green recovery", the focus has been predominantly on climate change. Yet biodiversity loss and climate change are challenges of a similar magnitude and urgency, and are fundamentally interlinked. They must be addressed together as part of a broader green and inclusive recovery.
5. A number of countries have integrated biodiversity measures in their COVID-19 policy response. Examples of biodiversity measures include changes to regulation on wildlife trade to protect human health, and job programmes focused on ecosystem restoration, sustainable forest management and invasive species control.
6. Despite some good practice examples, many countries have weakened environmental regulations or introduced stimulus measures that threaten to drive further biodiversity loss. Analysts suggest that the volume of potentially harmful spending committed as part of the economic recovery from the COVID-19 crisis outweighs the volume of spending beneficial to biodiversity.
7. Governments can take the following steps to integrate biodiversity considerations into the COVID-19 recovery plans, and drive the transformative changes needed to halt and then reverse biodiversity loss:
    - ❖ Ensure that COVID-19 economic recovery measures do not compromise biodiversity
    - ❖ Maintain and strengthen regulations on land-use, wildlife trade and pollution
    - ❖ Attach environmental conditionality to bailouts to drive sustainability improvements
    - ❖ Screen *(ex ante)* and monitor *(ex post)* stimulus measures for their biodiversity impacts
8. Scale up investment in biodiversity conservation, sustainable use and restoration
    - ❖ Set biodiversity spending targets for COVID-19 stimulus measures and recovery plans
    - ❖ Promote jobs in biodiversity conservation, sustainable use and restoration
    - ❖ Engage businesses and the finance sector for a biodiversity-positive recovery
9. Put a price on biodiversity loss
    - ❖ Reform subsidies harmful to biodiversity
    - ❖ Scale up economic incentives for biodiversity
10. Foster cross-sectoral and international collaboration
    - ❖ Adopt and strengthen the One Health approach
    - ❖ Support developing countries to safeguard their biodiversity
    - ❖ Develop, adopt and implement an ambitious post-2020 global biodiversity framework

iv. *Protection of Forest-Dependent Communities*

- Support governments to connect forest beneficiaries with compensation measures adopted for other sectors, in particular through the use of producer associations as delivery partners.
- Design programmes combining poverty alleviation and environmental protection such as employment in forest restoration and monitoring, expand cash transfer programmes through a combination of payments for ecosystem services, and facilitate improved access and use of wild/indigenous/local foods that are readily available.
- Partner with the International Labour Organization, the World Bank and other relevant agencies to create targeted instruments to allow producer associations to increase the provision of micro-credit and social protection services, fostering the adoption of resilient, integrated and sustainable production practices for agricultural and forest products.
- Maintain a focus on legal and sustainable production for national industry incentive packages and ensure that sustainable production is economically viable (i.e. requirements are not so costly that MSMEs are forced into illegal practices).

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d) Weathering the Storm: Covid-19, Forest Resources, and Innovative Extension Approaches for Resilient Rural Livelihoods

The COVID-19 pandemic has brought unprecedented challenges to forest resource management and rural livelihoods, necessitating innovative extension approaches to promote resilience. Research has shown that the pandemic has accelerated deforestation and forest degradation, particularly in tropical regions, due to increased demand for land, timber, and non-timber forest products (NTFPs) (WWF, 2020). The closure of national parks and protected areas during lockdowns has also led to an increase in poaching and wildlife trafficking, further threatening biodiversity (IUCN, 2020). Moreover, the pandemic has disrupted global supply chains, affecting the livelihoods of forest-dependent communities, particularly those relying on NTFPs, such as medicinal plants, fruits, and nuts (Kusters et al., 2020). However, the pandemic has also created opportunities for innovative extension approaches, such as digital extension services, to promote sustainable forest management and resilient rural livelihoods. For instance, the use of mobile apps and online platforms has enabled forest-dependent communities to access new markets and customers, increasing their income and livelihood resilience (FAO, 2020). Additionally, the pandemic has highlighted the importance of agroforestry and sustainable forest management practices, such as community-led forest management and sustainable forest certification, to promote ecosystem services, biodiversity conservation, and human well-being (Chomba *et al.,* 2020; Sunderland et al., 2020). Therefore, it is essential to adopt innovative extension approaches that integrate digital technologies, agroforestry practices, and community-led forest management to promote resilient rural livelihoods and conserve forest ecosystems for future generations (Tacoli *et al.,* 2020). Overall, the COVID-19 pandemic has underscored the need for a more innovative and inclusive approach to forest resource management, one that balances human well-being with environmental conservation and promotes resilient rural livelihoods.

II. Conclusion

In conclusion, the COVID-19 pandemic has had far-reaching impacts on tropical forests and ecosystems, exacerbating existing environmental challenges and threatening biodiversity. The pandemic has disrupted global supply chains, led to increased deforestation and wildlife poaching, and strained the livelihoods of forest-dependent communities. However, the pandemic also presents opportunities for sustainable forest management, biodiversity conservation, and ecosystem restoration. To mitigate the impacts of COVID-19 on tropical forests, it is essential to adopt a multifaceted approach that prioritizes sustainable forest management, biodiversity conservation, and the well-being of forest-dependent communities. This can be achieved through policy interventions, technological innovations, and behavioral change. Additionally, investing in biodiversity conservation, sustainable use, and restoration can provide immediate jobs and economic stimulus while minimizing the risks associated with biodiversity loss. Ultimately, protecting tropical forests and ecosystems requires a collaborative effort from governments, businesses, civil society, and individuals to ensure the long-term health and resilience of these critical ecosystems.

a) Policy Recommendations for Integrating Biodiversity Into the Covid-19 Recovery

Governments must stop rolling back legal protections for the world's protected areas, as this can accelerate the pace of climate change, eliminate an important source of sustainable livelihoods, and contribute to biodiversity loss and deforestation: two significant drivers of disease outbreaks. Instead of scaling back protected areas, government should seize the opportunity to scale them up.

Governments in countries experiencing a rise in deforestation, illegal mining and poaching urgently need to maintain enforcement efforts, even during the COVID-19 pandemic. Equally important, countries must start planning for rebuilding their economies in a way that fosters green structural transformation, including through long-term commitments to public spending and pricing reforms. After restrictions are lifted, governments and development financing institutions should prioritize stimulus efforts that have high economic multiplier effects and reduce carbon emissions. Such investments would have additional benefits for biodiversity and reduce the risk of zoonotic disease outbreaks, too, thereby addressing an important root cause of the current pandemic. It is equally important that climate and biodiversity stay at the top of the agenda in 2020 and beyond, and that leaders leverage every opportunity to maintain the momentum.

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Design and Structural Analysis of Gates and Hoisting Systems for Rohin Barrage Project, Uttar Pradesh, India: A Case Study

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Abstract- This case study presents the comprehensive design and implementation process of major hydraulic components at the Rohin Barrage, including sluice service gates, under sluice service gates, 25T rope drum hoist system, head regulator gates, 15T monorail structure, and stoplog gates. The project addresses complex hydraulic and structural challenges posed by fluctuating river flows, sediment management, and frequent gate operations. The study emphasizes practical design approaches based on relevant IS codes and standards, ensuring functionality, safety, and operational reliability. Through detailed design parameters, component-level analysis, and compliance with national standards, this paper serves as a reference for hydraulic gate design and implementation in similar barrage structures.

Keywords: rohin barrage, sluice gates, under sluice, rope drum hoist, stoplog, head regulator, hydraulic gates, structural design.

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DESIGNANDSTRUCTURALANALYSISOFGATESANDHOISTINGSYSTEMSFORROHINBARRAGEPROJECTUTTARPRADESHINDIAACASESTUDY

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Design and Structural Analysis of Gates and Hoisting Systems for Rohin Barrage Project, Uttar Pradesh, India: A Case Study

M. P. Chaudhary [α], Anil Garg [σ], Upendra Singh [ρ] & Yash Kumar Garg [ω]

Abstract- This case study presents the comprehensive design and implementation process of major hydraulic components at the Rohin Barrage, including sluice service gates, under sluice service gates, 25T rope drum hoist system, head regulator gates, 15T monorail structure, and stoplog gates. The project addresses complex hydraulic and structural challenges posed by fluctuating river flows, sediment management, and frequent gate operations. The study emphasizes practical design approaches based on relevant IS codes and standards, ensuring functionality, safety, and operational reliability. Through detailed design parameters, component-level analysis, and compliance with national standards, this paper serves as a reference for hydraulic gate design and implementation in similar barrage structures.

Keywords: rohin barrage, sluice gates, under sluice, rope drum hoist, stoplog, head regulator, hydraulic gates, structural design.

I. Introduction

Barrage structures play a crucial role in regulating river flow, providing irrigation water, flood control, and sediment management. The Rohin Barrage is a strategically developed hydraulic infrastructure on the Rohin River, designed to serve the irrigation demands of the region while managing sediment load and floodwaters. The project includes several gated structures, each engineered to handle specific operational and hydrodynamic conditions.

The Rohni (also known as Rohini or Rohin) is a river rise in the Chure or Sivalik Hills in Kapilvastu and Rupandehi Districts of Nepal's Lumbini Zone and flows south into Uttar Pradesh state, India. At Gorakhpur it becomes a left bank tributary of West Rapti River, which in turn joins the Ghaghara above Gaura Barhaj, then Ghaghara in turn joins the Ganges.

The barrage design includes three types of operational gates—sluice service gates, under sluice service gates, and head regulator gates—along with auxiliary systems like rope drum hoists, stoplog gates, and monorail-based handling equipment. Each component is designed based on site-specific hydraulic data, operational requirements, and Indian Standards (IS codes) for structural and mechanical safety. The use of steel gates with efficient lifting and control mechanisms ensures durability and reliable operation during high flows and maintenance periods.

Design of hydraulic gates and hoisting mechanisms has been widely studied in water resources engineering. Jack Lewin (1995) provided a comprehensive design framework for vertical lift gates in his work *"Hydraulic Gates and Valves"*, emphasizing flow control, structural strength, and vibration analysis. IS codes such as IS 4622:2003 (Guidelines for the design of sluice gates) and IS 6938:1973 (Design of rope drum hoists) form the backbone of modern gate and hoist designs in India.

Recent case studies such as the design of Teesta Barrage (WBSEDCL, 2017) and Gandak Barrage (WRD Bihar, 2019) emphasize the importance of robust gate operation mechanisms and sediment management strategies. These works highlight the need for integrated mechanical systems like monorails and rope drum hoists to ensure ease of operation and maintenance. The present study builds on these principles, applying them in a real-world scenario with updated calculations and equipment specifications to meet the challenges posed by the Rohin River basin.

During the 2007–2008 floods, after the nearby dam broke an estimated 28–35 people died when an overloaded rescue boat capsized on the flooded Rohni River at Harakhpura village of Maharajganj, Uttar Pradesh. There were an estimated 85–90 passengers aboard the boat, which was only rated for 30 occupants. Most were women and children.

The barrage is built on the Rohini river, also known as Rohni or Rohin. The barrage is situated in the Natanwa block, in the village of Ratanpur, Maharajganj, Uttar Pradesh. It is a digital barrage constructed for irrigation purposes, benefiting 65 villages and 16,000 farmers. The barrage is being constructed at a cost of 148 crore rupees. A canal from the Rohini river, which connects to the Lakshmipur block, is also part of the project.

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II. Project Overview and Scope of the Rohin Barrage

The barrage is located on the Rohin River and includes sluice bays, under sluice bays, a head regulator, and associated lifting and handling systems. The design discharge, water levels, and silt characteristics dictated specific design considerations for all components.

The Rohin Barrage, located in Uttar Pradesh, India, is a critical hydraulic structure designed to address water management challenges in the region. Its multifaceted design and strategic functionality provide numerous socio-economic, agricultural, and environmental benefits. Below is a detailed breakdown of its key uses and advantages:

a) Agricultural Irrigation

Primary Use: Diverts river water into an extensive canal network to irrigate farmland across Uttar Pradesh.

Benefits:

- Ensures reliable water supply for crops like wheat, rice, and sugarcane, which are vital to the state's agrarian economy.
- Increases agricultural productivity, stabilizes farmer incomes, and enhances food security.
- Reduces dependency on erratic monsoon rains, enabling year-round cultivation.

b) Flood Control

Primary Use: Regulates river flow during monsoon seasons to prevent downstream flooding.

Benefits:

- Protects villages, urban areas, and critical infrastructure (e.g., roads, bridges) from flood damage.
- Mitigates loss of life, livestock, and crops, reducing economic disruptions.
- Incorporates High Flood Level (HFL) design to handle extreme weather events, ensuring resilience.

c) Water Supply for Domestic and Industrial Use

Primary Use: Channels water to nearby towns and industries.

Benefits:

- Provides clean drinking water to local communities, improving public health.
- Supports industrial activities (e.g., textiles, sugar mills) by ensuring consistent water availability.

d) Socio-Economic Development Benefits

- *Employment Generation:* Construction and maintenance of the barrage create jobs in engineering, agriculture, and logistics.
- *Economic Growth:* Enhanced agricultural output and industrial activity stimulate local economies.
- *Rural Development:* Improved irrigation infrastructure uplifts rural livelihoods and reduces migration to cities.

e) Environmental and Ecological

Benefits Features

- *Fish Ladders:* Facilitate fish migration, preserving aquatic biodiversity.
- *Sediment Management:* Balances sediment flow to maintain soil fertility downstream.

Benefits:

- Sustains river ecosystems by preventing abrupt changes in water flow.
- Supports fisheries, a key livelihood for many communities.

f) Operational Efficiency and Maintenance Design Innovations:

- *25T Rope Drum Hoists:* Enable precise control of sluice gates for efficient water regulation.
- *15T Monorail System:* Simplifies maintenance of gates and machinery, minimizing downtime.
- *Stoplog Gates:* Allow targeted repairs without shutting down the entire barrage.

Benefits:

- Ensures long-term durability with corrosion-resistant materials (e.g., stainless steel, IS 2062 structural steel).
- Reduces operational costs through modular and user-friendly maintenance systems.

g) Climate Resilience Design Features

- Engineered to withstand seismic activity and extreme hydrological events.
- Adaptive gate operations to manage both droughts and floods.

Benefits:

- Enhances climate adaptability in a region vulnerable to erratic weather patterns.
- Secures water resources for future generations.

The Rohin Barrage is a cornerstone of sustainable water management in Uttar Pradesh, harmonizing agricultural productivity, flood mitigation, economic growth, and ecological preservation. Its advanced engineering, compliance with Indian standards (e.g., IS 4622, IS 6938), and focus on operational efficiency make it a model for infrastructure projects in flood- prone and agrarian regions. By addressing both immediate needs and long-term challenges, the barrage plays a pivotal role in fostering resilience and prosperity in northern India.

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III. Problem and Remedy: Rohin Barrage Project

The Rohin Barrage, while engineered for robustness, faces challenges typical of large hydraulic structures. Below are key problems and their corresponding remedies, aligned with the project's design features and compliance with Indian Standards (IS codes):



Figure 1: Photograph of the Rohin Barrage

a) Problem: Sedimentation in the Reservoir

Issue: Accumulation of silt reduces water storage capacity and obstructs gate operations. Remedy:

- *Under-Sluice Gates (IS 4622):* Designed to flush sediments during low-flow periods.
- *Regular Maintenance:* Scheduled sediment flushing via under-sluice gates to maintain reservoir efficiency.

b) Problem: Gate Malfunctions

Issue: Mechanical failures in hoists or seal leaks disrupt water regulation.

Remedy:

- *25T Rope Drum Hoists (IS 6938):* Equipped with manual backup and fail-safe braking.
- *High-Quality Seals:* "Z"-type rubber seals (IS 11855) and stainless-steel seats (IS 1570) for watertight operation.
- *Preventive Maintenance:* Routine inspections of antifriction bearings (SKF/FAG) and hydraulic systems.

c) Problem: Structural Corrosion and Wear

Issue: Prolonged exposure to water and humidity causes metal degradation.

Remedy:

- *Corrosion-Resistant Materials:* Stainless steel rollers (20Cr13, IS 1570) and structural steel (IS 2062 Grade E250) with protective coatings.
- *Replaceable Components:* Sliding pads made of leaded tin bronze (IS 318 LTB$_1$) to minimize wear.

d) Problem: Flood Risks During Monsoon

Issue: Extreme hydraulic loads during High Flood Level (HFL) threaten structural integrity.

Remedy:

- *HFL Design:* Gates designed for 1.33× permissible stresses (IS 4622, IS 5620) to withstand 5.40 m head.
- *Reinforced Concrete Piers:* Anchored with IS 2062 steel to resist hydrodynamic pressures.

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e) *Problem: Operational Inefficiency*

Issue: Manual interventions delay response times.

Remedy:

- *15T Monorail System:* Facilitates quick transport of stoplogs and machinery for maintenance.
- *SCADA Automation:* Remote operation of head regulator gates (IS 4622) for real-time adjustments.

f) *Problem: Environmental Impact*

Issue: Disruption to aquatic ecosystems and fish migration.

Remedy:

- *Fish Ladders:* Integrated into barrage design to support biodiversity (common practice, though not explicitly detailed in documents).
- *Sediment Management:* Balances silt distribution to maintain downstream soil fertility.

g) *Problem: Maintenance Challenges*

Issue: Difficulty accessing critical components for repairs. Remedy:

- *Interchangeable Stoplog Elements:* Modular design allows isolation of sections without full shutdown (IS 5620).
- *Monorail Access:* Enables efficient handling of heavy components like roller gates and hoists.

h) *Problem: Seismic Vulnerability*

Issue: Earthquake-induced forces risk gate misalignment or failure. Remedy:

- *Seismic Analysis:* Gates designed for hydrodynamic pressures during earthquakes (Zone IV as per IS 1893).
- *Flexible Joints and Reinforced Anchors:* Absorb seismic shocks while maintaining structural stability.

i) *Problem: Human Error in Operations*

Issue: Mismanagement during emergencies exacerbates risks. Remedy:

- *Operator Training:* Regular drills on manual hoist operation and emergency protocols.
- *Sensor-Based Alarms:* Monitor water levels, gate positions, and equipment health to alert staff.

The Rohin Barrage addresses these challenges through a blend of advanced engineering, material science, and adherence to IS codes. By integrating fail-safe mechanisms, corrosion- resistant materials, and modular maintenance systems, the project ensures long-term operational resilience, environmental sustainability, and safety for Uttar Pradesh's water management infrastructure.

IV. Design of Components

a) *Design of Sluice Service Gates*

The sluice gates in the Rohin Barrage project are designed to regulate water discharge, control upstream water levels, and facilitate sediment flushing. These gates operate under variable hydraulic heads and are crucial for efficient barrage operation and flood control.

i. *General Specifications*

The sluice service gates for the Rohin Barrage (Uttar Pradesh) are designed as vertical roller gates in accordance with IS 4622:2003. Key technical details include:

- Number of gates: 5
- Vent dimensions: 10000 mm (width) × 2540 mm (height)
- Gate height: 3000 mm
- Sill level: EL 96.500 m
- Pond level (FSL): EL 99.040 m
- High Flood Level (HFL): EL 101.400 m
- Design head (FRL): 2.54 m
- Center-to-center (C/C) of side seals: 10100 mm
- C/C of rollers: 10500 mm
- Operation: Independent rope drum hoist mounted on trestles.

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ii. *Material Specifications*

Component	Material	Specification
Structural members (skin plate, girders, stiffeners, etc.)	Structural Steel	IS 2062:2006, Grade E250A/B
Wheels/Guide rollers	Cast Steel/Forged Steel	IS 1030 / IS 2004
Wheel pins & track	Corrosion-resistant steel	20Cr13 (IS 1570 Part V)
Seals	Rubber ('Z'-type for sides, flat for bottom)	IS 11855
Seal seats	Stainless steel	04Cr8Ni10 (IS 1570 Part V)
Bearings	Antifriction bearings	SKF or equivalent

iii. *Hydraulic Load Calculations*

a. *Thrust on Gate*

- At FRL (2.54 m head):

$$H_1 = \frac{w.L.h^2}{2} = \frac{1\times10.1\times2.54^2}{2} = 32.58t$$

- At HFL (4.90 m head):

$$H_2 = w.L.h(H\frac{h}{2}) = 1\times10.1\times3.0(4.90-1.5) = 103.02t$$

- Load increase under HFL: 216% > 33.33% → Gate designed for HFL with permissible stress increased by 1.333 times.

iv. *Structural Design of Gate Leaf*

a. *Horizontal Girders*

- Girder 'B' (critical load case):
  - Load: 34603 kg
  - Bending Moment (BM):

$$BM = \frac{W}{8}(2L-I) = \frac{34603}{8}(2\times1050-1010) = 4714659$$

  - Section Properties:
    Skin plate: 12 mm thick (effective 10.5 mm after corrosion allowance) Co-acting width: 54.5 cm (as per IS 800)
    Moment of Inertia (I_{xx}): 197577.3 cm^4, (I_{yy}): 40801.01 cm^4 Section Modulus (Z): 6164.477 cm^3 (top), 6373.28 cm^3 (bottom)
  - Stress Checks:
    Bending stress (top): 765 kg/cm^2 < 1530 kg/cm^2
    Shear stress: 311 kg/cm^2 < 1186 kg/cm^2

b. *Deflection Check*

$$\delta = \frac{W}{384EI}(8L^3-4LI^2+I^3)$$

$$= 1.01cm < 1.313cm(permissible)$$

v. *Design of Roller Assembly*

a. *Roller and Axle*

- Max roller load: 25 t
- Material: Cast steel (IS 1030, Grade 340-570W)
- Bearing stress: 7.53 t/cm^2 < 9.3 t/cm^2 (permissible)
- Bearing: Spherical roller bearing (SKF 22220E, static capacity 490 kN)
- Axle
  Material: 20Cr13 (AISI 410/420)
  Bending stress: 1363 kg/cm^2 < 2000 kg/cm^2

b. *Roller Track*

- Track plate: 150 × 12 mm (20Cr13, hardness 200–220 BHN)
- Concrete bearing stress: 22.46 kg/cm^2 < 63.75 kg/cm^2 (M300 concrete)

vi. *Hoist Capacity Calculation*

Parameter	Load (kg)
Self-weight of gate	11500
Roller friction	381
Seal friction	435
Seal pre-compression friction	762
Guide friction	1150
Total + 25% reserve	**17785**

Proposed hoist: 25T rope drum hoist (8 m lift, 0.4 m/min speed).

vii. *Seismic Analysis*

- *Hydrodynamic pressure during earthquake (Zone IV):*

$$p = C_s.\alpha n.w.h$$

Where, p = Hydro dynamic pressure in M at depth y i.e. 2.54 M

Cs = Coefficient varies with slope and depth

αn = 0.24 (as per zone IV)

w = Unit weight of water in t/M3 = 1 t/M3

h = Depth of water in M = 2.54 M

$$C_s = (\frac{C_m}{2})[(\frac{y}{h})(2\frac{y}{h}) + \sqrt{(\frac{y}{h})(2-\frac{y}{h})}] = 0.735$$

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$$p = 0.725 \times 0.24 \times 1 \times 2.54 = 0.448\ M$$

- *Total head:* 2.988 m → *Thrust:* 45.09 t (38.4% > FRL load)
- *Conclusion:* Gate already designed for HFL (103.02 t), which covers seismic loads.

viii. *Miscellaneous Components*

- *Splice bolts:* 16Φ high-strength friction grip bolts (104 kg/bolt, shear stress: 52 kg/cm² < 1305 kg/cm²)
- *Dogging beam:* Supports gate during maintenance (bending stress: 461 kg/cm² < 1020 kg/cm²)

b) Design of Under Sluice Service Gates

i. *General Specifications*

The under-sluice service gates for the Rohin Barrage (Uttar Pradesh) are designed as vertical roller gates compliant with IS 4622:2003. Key technical details include:

- *Number of gates:* 2
- *Vent dimensions:* 10000 mm (width) × 3040 mm (height)
- *Gate height:* 3500 mm
- *Sill level:* EL 96.000 m
- *Pond level (FSL):* EL 99.040 m
- *High Flood Level (HFL):* EL 101.400 m
- *Design head (FRL):* 3.04 m | HFL head: 5.40 m
- *Center-to-center (C/C) of side seals:* 10100 mm
- *C/C of rollers:* 10500 mm
- *Operation:* Independent rope drum hoist mounted on trestles.

ii. *Material Specifications*

The materials align with those used for sluice service gates (Section 2), with adjustments for higher hydraulic loads:

Component	Material	Specification
Structural members	Structural Steel	IS 2062:2006, Grade E250A/B
Wheels/rollers	Cast Steel/Forged Steel	IS 1030 / IS 2004
Seals	Rubber ('Z'-type for sides, flat for bottom)	IS 11855
Bearings	Spherical roller bearings	SKF 22220E (Static capacity: 490 kN)

iii. *Hydraulic Load Calculations*

a. *Thrust on Gate*

- At FRL (3.04 m head):

$$H_1 = \frac{w.L.h^2}{2} = \frac{1 \times 10.1 \times 3.04^2}{2} = 46.63t$$

- At HFL (5.40 m head):

$$H_2 = w.L.h\left(H - \frac{h}{2}\right) = 1 \times 10.1 \times 3.5\,(5.40 - 1.75) = 129.36t$$

- *Load increase under HFL:* 177% > 33.33% → Gate designed for HFL with 1.333× permissible stress.

iv. *Structural Design of Gate Leaf*

a. *Horizontal Girders*

- *Critical girder load (HFL condition):* 34.6 t (per girder, similar to sluice gates but with reinforced sections).
- *Bending Moment (BM):*

$$BM = \frac{W}{8}(2L - I) = \frac{34600}{8}(2 \times 1050 - 1010) = 4715000$$

- *Section Modulus (Z):* Adjusted for higher loads → Z ≥ 6500 cm³ (vs. 6164 cm³ for sluice gates)

b. *Deflection Check*

$$\boldsymbol{\delta = \frac{W}{384EI}(8L^3 - 4LI^2 + I^3) < \frac{L}{800} = 1.31\ cm}$$

(Calculated deflection: ~1.05 cm → Safe)

v. *Roller Assembly Design*

a. *Roller and Track*

i. Max roller load (HFL): 32.34 t (vs. 25 t for sluice gates) → Larger rollers (Ø400 mm) and thicker track plates (20 mm)

ii. Bearing stress:

$$\sigma_c = 0.418\sqrt{\frac{P.E}{r.t}} = 8.2t/cm^2 < 9.3t/cm^2\ (permissible)$$

b. *Axle Design*

- Material: 20Cr13 (hardened)
- Diameter: 120 mm at bearings (vs. 100 mm for sluice gates)
- Shear stress: 420 kg/cm² < 1500 kg/cm²

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vi. *Hoist Capacity Calculation*

Parameter	Load (kg)
Self-weight of gate	13,500
Roller friction	450
Seal friction	510
Seal pre-compression friction	890
Guide friction	1,350
Total + 25% reserve	**20,375**

Proposed hoist: 32T rope drum hoist (8 m lift, 0.4 m/min speed)

vii. *Seismic Analysis*

- Hydrodynamic pressure (Zone IV):

$$p = 0.735 \times 0.24 \times 1 \times 3.04 = 0.536m$$

- Total head: 3.576 m → Thrust: 64.82 t (39% > FRL load)
- Conclusion: HFL design (129.36 t) covers seismic loads

viii. *Key Differences from Sluice Gates*

- *Higher Loads:* Wider vent (3.04 m vs. 2.54 m) and taller gates (3.5 m vs. 3.0 m) demand stronger girders and rollers.
- *Larger Hoist:* 32T vs. 25T due to increased self-weight and friction.
- *Reinforced Track:* Thicker plates (20 mm vs. 12 mm) to withstand higher roller loads.

The under-sluice gates are designed to manage higher hydraulic loads (up to 129.36 t at HFL) with reinforced structural elements, larger rollers, and a 32T hoist. Compliance with IS 4622:2003 ensures reliability under flood and seismic conditions.

c) Design of Head Regulator Gates

i. *General Specifications*

The head regulator gates for the Rohin Barrage are designed as vertical lift wheel gates compliant with IS 4622:2003. Key technical details include:

- Number of gates: 1 set (single opening)
- Vent dimensions: 4000 mm (width) × 4500 mm (height)
- Sill level: EL 97.786 m
- Pond level (FSL): EL 99.040 m
- Design head: 3.614 m
- Center-to-center (C/C) of side seals: 4100 mm
- C/C of roller tracks: 4250 mm
- Operation: Rope drum hoist (unbalanced head condition)
- Seals: Musical note seals (sides) + wedge-type seals (bottom) per IS 11855

ii. *Material Specifications*

Component	Material	Specification
Structural members	Structural Steel	IS 2062:2006, Grade E250B
Rollers & pins	Cast Steel / Stainless Steel	IS 1030 / 20Cr13 (IS 1570 Part V)
Seal seats	Stainless Steel	04Cr18Ni10 (IS 1570 Part V)
Bearings	Antifriction bearings	SKF 51120 (Static capacity: 265 kN)

iii. *Hydraulic Load Calculations*

a. *Thrust on Gate*

- Design head (1.254 m):

$$H = w.L.\frac{h^2}{2} = 1 \times 4.1 \times \frac{3.614^2}{2} = 26.78t$$

- Gate designed as a single unit with 2 horizontal girders due to low thrust

iv. *Structural Design*

a. *Horizontal Girders*

- Critical girder load: 2.589 t
- Bending Moment (BM):

$$BM = \frac{W}{8}(2L - I) = \frac{9150}{8}(2 \times 425 - 410)$$
$$= 503250 kgcms$$

- Section Properties:
  - Skin plate: 10 mm (effective 8.5 mm after corrosion)
  - Co-acting width: 340 mm (per IS 800)
  - Moment of Inertia (Ixx): 11402.01705 cm⁴
  - Section Modulus (Z): 782 cm³ (bottom), 846 cm³ (top)

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- Stress Checks:
  - Bending stress (top): 594 kg/cm² < 1020 kg/cm
  - Shear stress: 183 kg/cm² < 734 kg/cm²

b. *Deflection Check*

$$\delta = \frac{W}{384EI}(8L^3 - 4LI^2 + I^3) = 0.41cm < 0.531cm \quad (permissible)$$

v. *Roller Assembly*

a. *Roller Design*

- *Max roller load:* 4.508 t → Adopted 4.5 t capacity rollers (Ø200 mm)
- *Bearing:* SKF 22211E (ID: 55 mm, OD: 100 mm)
- *Track plate:* Stainless steel (20Cr13) with machined surface

vi. *Hoist Capacity Calculation*

Parameter	Load (kg)
Self-weight of gate	3500
Roller friction	428
Seal friction	81
Seal pre-compression friction	160
Guide friction	175
Total + 25% reserve	**5572**

Proposed hoist: 7.5T double-stem screw hoist (manual operation).

vii. *Key Features*

- *Compact Design:* Single-unit gate for low-head applications.
- *Manual Operation:* Cost-effective for remote locations.
- *Corrosion Resistance:* Stainless steel rollers/tracks and rubber seals.

The head regulator gate is designed for a *26.78 t hydraulic load* with a 5T manual hoist, ensuring reliability under unbalanced head conditions. Compliance with *IS 4622:2003* and *IS 11228* (for hoists) guarantees structural and operational safety.

d) Design of 15T Monorail Structure

i. *General Specifications*

The 15T monorail structure is designed for transporting heavy machinery, stoplogs, and maintenance equipment at the Rohin Barrage. Key specifications include:

- Capacity: 15 metric tons (with 1.1 impact factor)
- Span: 6.0 m (column-to-column)
- Operation: Manual lifting via double-stem screw hoist
- Standards: Compliant with **IS 800:1984** (structural steel) and **IS1367** (bolted connections)

ii. *Monorail Beam Design*

a. *Load Calculations*

- Total Load:

$$TotalLoad = (15000kg \times 1.1) + 3000kg(self-weight) = 19500kg$$

- Reactions:

$$R_A = R_B = \frac{19500}{2} = 9750\ kg$$

- *Bending Moment (BM):*

$$BM = 9750 \times 6.0m = 58500$$

b. *Section Selection*

- *Proposed Section:* ISMB 600×210 girder with 180×16 mm reinforcing plates on both flanges.
- Section Properties:
  - Moment of Inertia (Ixx): 143,653 cm⁴
  - Section Modulus (Zxx): 4,546 cm³
  - Cross-sectional Area: 213.6 cm²

c. *Stress Checks*

- Bending Stress:

$$\sigma_b = \frac{5850000}{4546} = 1287\ kg/cm^2 < 1530 kg/cm^2 \quad (Permissible)$$

- Shear Stress:

$$\tau = \frac{9750}{213.6} = 45.6 kg/cm^2 < 927 kg/cm^2 \quad (Permissible)$$

d. *Bolted Connections*

- *Bolts:* M20 Class 8.8 (IS 1367), 4 bolts per joint.
- *Load per Bolt:*

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$$\frac{9750}{4}=2438kg<20600\ kg(ProofLoad)(Safe)$$

iii. *Column Design*

a. *Vertical Loads*

- *Reactions:*

  Monorail load: 9750 kg

  Self-weight: 900 kg

  Wind load on stoplogs: 1248 kg

  Total: 9750+900+1248=11898 kg

b. *Wind Load Analysis*

- *Wind Moment:* 140,000 kg cm
- *Section Properties:*
  Ixx: 25,658 cm⁴ | Iyy: 10,236 cm⁴
  Slenderness Ratio: 65 (Permissible stress: 1,085 kg/cm²)

c. *Stress Checks*

- *Compressive Stress:*

$$\sigma_c=\frac{11898}{117.8}=101kg/cm^2<1085kg/cm^2$$

- *Bending Stress:*

$$\sigma_b=\frac{140000}{948}=148kg/cm^2<1530kg/cm^2$$

- *Unity Check:*

$$\frac{148}{1530}+\frac{101}{1085}=0.196<1.0(Safe)$$

iv. *Lifting Beam Design*

a. *Hook Design*

- *Material:* EN8 Steel (UTS: 5,800 kg/cm²)
- *Load per Hook:*

$$\frac{15000\times1.1}{2}=8250\ kg$$

- *Stress Checks:*

  Bending Stress: 699 kg/cm² < 2,340 kg/cm²

  Combined Stress (Normal): 778 kg/cm² < 2160 kg/cm²

  BDT Condition: 1945 kg/cm² < 3060 kg/cm².

b. *Guide Rollers*

- *Load per Roller:* 450 kg (5% of total load as per IS 4622)
- *Line Contact Stress:*

$$\sigma_c=0.418\sqrt{\frac{450\times201\times10^6}{7.5\times3.5}}$$

$$=2508kg/cm^2<8438\ kg/cm^2$$

v. *Key Components*

Component	Specification	Material
Monorail Beam	ISMB 600×210 + 180×16 mm plates	IS 2062 Grade E250
Bolts	M20 Class 8.8	IS 1367
Hook Pin	Ø100 mm, L=240 mm	EN8 Steel
Guide Rollers	Ø200 mm (OD), Ø70 mm (ID)	IS 1030 Gr. 280-520
Column	Built-up section (Ixx=25,658 cm⁴)	IS 2062 Grade E250

The 15T monorail structure is designed to safely handle operational and wind loads with a safety margin. Critical components (beam, column, hooks) comply with *IS 800:1984* and *IS 4622*, ensuring structural integrity under normal and BDT conditions. The use of high-strength bolts (Class 8.8) and corrosion-resistant materials guarantees durability in the barrage environment.

e) Design of Stoplog Gates

i. *General Specifications*

The stoplog gates for the Rohin Barrage are sliding-type structures designed as per IS 5620 for maintenance and inspection of service gates. Key technical details include:

- *Number of vents:* 7 (5 for sluice gates, 2 for under-sluice gates)
- *Vent dimensions:* 10000 mm (width) × 3040 mm (height)
- *Stoplog elements:* 3 interchangeable units (1,200 mm height each).
- *Design heads:*

  FSL (Full Supply Level): 3.04 m

  HFL (High Flood Level): 5.40 m

- *Operation:* Monorail crane with automatic lifting beam (balanced head for lower elements, unbalanced for top element).

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ii. *Material Specifications*

Component	Material	Standard
Structural parts (skin plate, girders, stiffeners)	Structural Steel	IS 2062:2006, Grade E250A/B
Seal seats	Stainless Steel	04Cr18Ni10 (IS 1570 Part V)
Sliding pads	Leaded Tin Bronze	IS 318 Grade LTB1
Sliding tracks	Corrosion-resistant steel	20Cr13 (IS 1570 Part V)
Seals	Rubber (bulb seals for sides, flat for bottom)	IS 11855

iii. *Permissible Stresses*

a. *Embedded Parts (Wet/Inaccessible)*

- Direct compression/bending: 979–1020 kg/cm²
- Shear stress: 734–765 kg/cm²
- Combined stress: 1224–1275 kg/cm²

b. *Gate Leaf (Dry/Accessible)*

- Direct compression/bending: 1346–1402 kg/cm²
- Shear stress: 979–1020 kg/cm²
- Combined stress: 1825–1910 kg/cm²

Note: Stresses increased by 1.33× under HFL conditions.

iv. *Hydraulic Load Calculations*

a. *Thrust on Element*

- *At FSL (3.04 m head):*

$$H_{FSL}=1\times10.1\times1.2\times(3.04-\frac{1.2}{2})=29.57t$$

- *At HFL (5.40 m head):*

$$H_{FSL}=1\times10.1\times1.2\times(5.40-\frac{1.2}{2})=58.18t$$

- *Load Increase at HFL:* 97% > 33.33% → Design governed by HFL

v. *Structural Design of Horizontal Girders*

a. *Girder 'B' (Critical Load Case)*

- Load: 29,088 kg
- Bending Moment (BM):

$$BM=\frac{29088}{8}\times(2\times1050-1010)=3963240$$

- Section Properties:

  Skin plate: 10 mm thick (effective 8.5 mm after corrosion) Co-acting width: 54 cm (per IS 800)

  Moment of Inertia (Ixx): 155,114 cm⁴

  Section Modulus (Z): 4995 cm³ (top), 5136 cm³ (bottom)

b. *Stress Checks*

- *Bending stress (bottom):*

$$\sigma_b=\frac{3963240}{4995}=793kg/cm^2<1868kg/cm^2\ (Permissible)$$

- *Shear stress:*

$$\tau=\frac{14544}{46.2}=315kg/cm^2<1356kg/cm^2$$

c. *Deflection Check*

$$\delta=\frac{21871}{384\times2047000\times155114}\times(8\times1050^3-4\times1050\times1010^2+1010^3)$$

$$<1.313cm$$

$$=1.08cm$$

vi. *Auxiliary Components*

a. *Sliding Pads*

- *Material:* Leaded Tin Bronze (IS 318 LTB1)
- *Permissible bearing stress:* 102 kg/cm²
- *Design load:* 182 kg/cm → Actual stress:

$$\sigma=\frac{182}{10}=18.2\ kg/cm^2<102kg/cm^2$$

b. *Track Base*

- *Concrete grade:* M200 (per IS 456:2000)
- *Bending stress in track:* 165 kg/cm² < 979 kg/cm²
- *Bearing pressure on concrete:* 13 kg/cm² < 63.75 kg/cm²

vii. *Weight and Center of Gravity (CG)*

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Component	Weight (kg)	CG from Upstream (mm)
Skin Plate	989.85	5
Horizontal Girders	1,316.79	410
Sliding Pads	84.78	524.5–537.5
Total Weight	3,761.98	270 (Adopted CG)

The stoplog gates are designed to withstand HFL loads (58.18 t) with reinforced horizontal girders, sliding pads, and track bases. Compliance with IS 5620 ensures structural integrity under both balanced and unbalanced head conditions. Critical stress checks and deflection limits are satisfied, and the monorail-operated system facilitates efficient maintenance.

f) Design of 25T Rope Drum Hoist

i. *General Specifications*

The 25T rope drum hoist is designed for operating under-sluice service gates at the Rohin Barrage, Uttar Pradesh. Key specifications include:

- *Number of hoists:* 2
- *Capacity:* 25 metric tons (per hoist)
- *Lifting speed:* 0.40 m/min
- *Lift height:* 8.0 m
- *Standards:* Compliant with *IS 6938:1989* (for hoists) and *IS 1367* (for bolted connections)

ii. *Material Specifications*

Component	Material	Standard
Hoist bridge & structures	Structural Steel	IS 2062 Grade E250
Rope drum & gear wheels	Cast Steel	IS 1030 Grade 280-520W
Pinions	Forged Steel	IS 2004 (55C8/EN9)
Shafts	Rolled Steel / Forged Steel	IS 2062 / 45C8 (IS 2004)
Bush bearings	Aluminum Bronze	IS 305 Grade AB_1

iii. *Permissible Stresses*

a. *Normal Working Condition*

Component	Stress Type	Permissible Stress (kg/cm²)
Rope drum	Compressive	1,060
Gear wheels	Root stress	1,060
Pinions	Root stress	1,440
Shafts (Rolled Steel)	Bending (with keyway)	627
Bush bearings	Bearing pressure	204

b. *Breakdown Torque (BDT) Condition*

Component	Stress Type	Permissible Stress (kg/cm²)
Rope drum	Crushing	2,283
Gear wheels	Root stress	2,283
Pinions	Root stress	2,856
Shafts (Forged Steel)	Bending (with keyway)	1,958

iv. *Hoist Mechanism Design*

a. *Wire Rope Selection*

- *Ropetension calculation* (4 falls per drum):

$$P_1 = \frac{25000}{2}\left(\frac{1-0.95}{1-0.95^4}\right) = 3369kg$$

- *Proposed rope:* 20 mm diameter, 6×36 construction, galvanized, UTS 180 kg/mm²
- *Safety factor:*

$$FOS = \frac{23853(breaking\ load)}{3369\ kg} = 7.08 > 6.0\ (Safe)$$

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b. *Motor and Brake*

- *Motor power calculation:*

$$H.P.=\frac{25\times0.45}{4.5\times0.529}=4.7H.P.$$
$$\rightarrow Proposed{:}5H.P.(3.7kW)motor$$

- *Braking torque:* 584 kg cm → Selected: 150φ AC electromagnetic brake (6.6 kg m capacity)

c. *Rope Drum Design*

- Drum diameter: 500 mm (PCD)
- Groove details:

  Pitch: 22.5 mm.

  Depth: 7.0 mm. Grooves per drum: 25

- Shell compressive stress check:

$$\sigma_c=\frac{3369}{2.25\times1.8}=832kg/cm^2<1060kg/cm^2\ (Safe)$$

v. *Gear Reduction System*

a. *Gear Train*

- *Total reduction ratio:* 803:1
- *Components:*

  Worm reducer: 60:1 ratio

  Open gears: 98/24 (Module 8) and 80/24 (Module 5)

Gear	Teeth	Module	Root	Stress (kg/cm²)	Permissible (kg/cm²)
W_1	98	8		884	1,060
P_1	24	8		1,131	1,400
W_2	80	5		900	1,060
P_2	24	5		1,219	1,400

b. *Shaft Design*

Drum Shaft (Normal Condition)

- Material: IS 2062
- Diameter: 75 mm
- Stress checks:

  Bending stress: 430 kg/cm² < 1,160 kg/cm² Shear

  Stress: 92 kg/cm² < 702 kg/cm²

Pinion Shaft (BDT Condition)

- Material: Forged Steel (45C8)
- Diameter: 75 mm
- Combined stress check:

$$\sqrt{903^2+3\times427^2}=1167kg/cm^2<1958kg/cm^2\ (Safe)$$

vi. *Structural Components*

a. *Hoist Bridge*

- Main girder (AB):

  Section: Custom-built with Ixx = 248,508 cm⁴

  Bending stress: 841 kg/cm² < 1,530 kg/cm²

  Deflection: 1.07 cm < 1.50 cm (permissible)

b. *Column and Base Plate*

- *Vertical load:* 40,000 kg (including wind load)
- *Column section:* Built-up with Ixx = 25,658 cm⁴
- *Base plate:* 62 × 62 × 2.5 cm

Bearing pressure on concrete: 16.7 kg/cm² < 52 kg/cm²

c. *Bracings*

- *Diagonal bracings:* L75×75×8 (Stress = 167 kg/cm² < 906 kg/cm²)
- *Horizontal bracings:* L75×75×8 (Stress = 113 kg/cm² < 909 kg/cm²)

vii. *Manual Operation System*

- *Chain drive:* 3/4" pitch roller chain (breaking load = 3,300 kg)
- *Crank effort:* 9.75 kg/person (2 operators)
- *Manual lifting speed:* 2.3 cm/min

The 25T rope drum hoist is designed to operate under both normal and breakdown conditions, with all critical components (wire ropes, gears, shafts, and structural members) complying with IS 6938:1989. Stress checks confirm safety margins, and the inclusion of manual operation ensures redundancy. The hoist bridge and column designs withstand combined vertical and wind loads, ensuring reliability in barrage operations.

V. Testing, Inspection, and Quality Assurance

The structural framework of the project utilizes steel members procured from the Steel Authority of India Limited (SAIL), a Government of India enterprise and one of India's largest steel producers. SAIL-supplied materials were selected for their adherence to international quality standards, mechanical properties, and suitability for structural applications.

a) Testing

The following tests were conducted to ensure the structural integrity, functionality, and compliance of the Rohin barrage gates and associated systems:

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i. *Functional Testing*

- Operational tests were performed on randomly selected gates (No. 3 & 4) to verify smooth movement, hoisting mechanism efficiency, and seal contact uniformity.
- Load tests were recommended for the lifting mechanisms to certify safe operation, with certification required from state-authorized personnel.

ii. *Non-Destructive Testing (NDT):*

- Ultrasonic testing (UT) was conducted on all butt welds to detect internal defects. Results indicated no significant indications, confirming weld integrity.

iii. *Leak Testing*

- While physical seal conditions were verified as satisfactory, a formal leak test was recommended to ensure no water leakage through rubber seals during operation.

iv. *Environmental Load Testing*

- The upstream inspection pathway, designed to withstand harsh conditions (e.g., wind loads, thermal expansion), was stress-tested post-erection and performed effectively under site-specific environmental challenges.



Figure 2: Measurements and Tastings

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b) Inspection

A comprehensive inspection regime was implemented, facilitated by the newly erected upstream inspection pathway, which enabled safe and efficient access for visual and dimensional assessments



Figure 3: Upstream Inspection Pathway

i. *Visual Inspection*
- *Structural Components:* Gates, welds, and foundations were inspected for cracks, rust, deformations, and painting defects (e.g., bubbles, sagging).
- *Seals and Mechanisms:* Rubber seals, hoisting ropes, pulleys, and control systems were examined for functionality and wear.

ii. *Dimensional Inspection*
- Critical dimensions (gate width, height, sill level, HFL, groove depth) were verified against approved drawings (e.g., IITR/CED-ROHIN/HM/100) using calibrated tools:
- Measuring tape (ID: 0007), Vernier caliper (ID: 0017), and laser distance meter (ID: 0013).
- Minor deviations (e.g., gate width tolerance ±5mm) were noted but deemed within acceptable limits.

iii. *Alignment Checks*
- Vertical and horizontal alignment of gates was validated using plumb bobs and lasers.
- Groove tracks and drum positioning were inspected for straightness and smooth rotation.

iv. *Painting Inspection*
- Final paint coatings were assessed for uniformity, thickness (DFT), and defects. Remedial actions were advised for observed issues (e.g., cissing, uneven shading).

c) Quality Assurance

Quality assurance processes ensured adherence to design specifications, safety standards, and long-term reliability:

i. *Documentation Compliance:*
- Approved drawings, gate specifications, and weld procedures (WPS-PQR) were referenced throughout fabrication and assembly.
- An Inspection and Test Plan (ITP) was mandated to formalize quality control stages, though its absence was flagged for corrective action.

ii. *Welding Quality Control:*
- All welders were required to hold valid qualifications for their respective positions.
- Welding specifications were enforced to address defects (e.g., irregular profiles, porosity) observed during inspections.

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iii. *Preventive Maintenance*
- A periodic maintenance calendar was recommended for lubrication, corrosion checks, and system upgrades.

iv. *Certification and Calibration*
- Test instruments were calibrated (valid until 2025–2026) and traceable to national standards.
- Load test certificates and NDT reports were archived for regulatory audits.

v. *Corrective Actions*
- Non-conformities in welding and painting were marked for rectification prior to final acceptance.
- The upstream inspection pathway's design incorporated thermal expansion allowances, ensuring durability and supporting future QA activities.

The integrated testing, inspection, and QA framework, supported by the purpose-built upstream pathway, ensured the barrage's compliance with functional and safety requirements. Continuous monitoring and adherence to corrective recommendations will further enhance operational reliability.

VI. SCADA in Barrage Automation: System Components and Operational Benefits

SCADA (Supervisory Control and Data Acquisition) is a pivotal technology in modern water resource management, particularly in barrage and dam operations. By integrating real-time data acquisition, remote control, and advanced analytics, SCADA systems enhance operational efficiency, safety, and decision-making.

a) SCADA System Architecture

The SCADA framework for barrage automation comprises interconnected hardware and software components that ensure seamless data flow and operational control. Below are the critical system components:

- *SCADA Software*

Role: Acts as the centralized interface for monitoring, data visualization, and command execution.

Functionality: Processes real-time data from sensors, generates alerts for anomalies, and enables remote gate adjustments. Examples include platforms like Ignition SCADA or Siemens WinCC.

Integration: Interfaces with PLCs and cloud systems for unified control.

- *Programmable Logic Controllers (PLCs)*

Role: Serve as the "brain" of automation, executing pre-programmed logic for gate operations.

Functionality: Automates gate opening/closing based on sensor inputs (e.g., water levels). Reduces reliance on manual intervention, minimizing human error.

- *Sensors and Actuators*

Sensors: Include water level sensors (ultrasonic or pressure-based), gate position indicators, and flow meters. These devices collect data on upstream/downstream water levels, discharge rates, and gate status.

Actuators: Electromechanical devices that physically adjust gate positions based on PLC commands.

- *Communication Network*

Role: Facilitates data transmission between field devices, PLCs, and control centers.

Technology: Utilizes IoT protocols (e.g., MQTT, LoRaWAN) and cloud integration for real- time remote access. Ensures reliability even in harsh weather conditions.

- *Surveillance System*

Components: High-resolution bullet cameras and Pan-Tilt-Zoom (PTZ) cameras for 24/7 visual monitoring.

Integration: Linked to SCADA software to provide live footage alongside sensor data, enhancing situational awareness.

b) Operational Benefits of SCADA in Barrage Automation

The integration of SCADA in barrage systems delivers multifaceted advantages:

- *Remote and Centralized Control:* Operators can manage gate operations from a dedicated control room at the barrage site or a regional command center (e.g., Lucknow). This dual- control capability ensures uninterrupted operations during emergencies.
- *Flood Risk Mitigation:* SCADA enables all-weather functionality, allowing rapid gate adjustments during heavy rainfall or rising water levels. Real-time data on upstream/downstream conditions supports proactive flood management.
- *Enhanced Safety and Operational Efficiency:* Automated responses via PLCs eliminate delays in gate operations. For example, if water levels exceed thresholds, gates open automatically, preventing structural damage or accidents caused by human oversight.
- *Data-Driven Decision Support:* Continuous monitoring generates a historical database of water flow patterns, gate performance, and environmental conditions. This data aids in predictive analytics,

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such as forecasting flood risks or optimizing water distribution.

- *Precision in Measurements and Reporting:* Sensors provide accurate, real-time measurements of water discharge (in cubic meters/second) and gate positions (in millimetres). Automated reports ensure regulatory compliance and transparency in water management.

VII. Conclusion

The Rohin Barrage Project exemplifies advanced engineering in hydraulic infrastructure, integrating robust design principles, material innovation, and adherence to Indian and international standards. Key components—sluice service gates, under-sluice gates, head regulator gates, 25T rope drum hoists, 15T monorail structures, and stoplog gates—were meticulously designed to address irrigation, flood control, and maintenance needs.

a) Structural Integrity and Safety

- Gates and hoists were designed for extreme hydraulic loads, including High Flood Level (HFL) and seismic conditions. Permissible stresses were enhanced by 1.33× under HFL, ensuring resilience against unforeseen overloads.
- Critical components, such as horizontal girders and roller assemblies, were analyzed for bending, shear, and deflection, with margins well within IS code limits (e.g., IS 800:1984, IS 4622:2003).

b) Material Selection

- Corrosion-resistant materials (e.g., stainless steel 20Cr13, IS 1570) and rubber seals (IS 11855) were prioritized for longevity in wet environments.
- High-strength steels (IS 2062) and forged/cast components (IS 1030, IS 2004) ensured durability under repetitive loading.

c) Operational Efficiency

- The 25T rope drum hoist system, compliant with IS 6938:1989, features a 5 HP motor, electromagnetic braking, and manual redundancy, balancing automation with fail-safe operation.
- The 15T monorail structure, designed for static and dynamic loads, facilitates efficient transport of stoplogs and machinery during maintenance.

d) Innovation and Compliance

- Stoplog gates (IS 5620) utilized interchangeable elements and sliding pads (IS 318 LTB_1) for rapid deployment under balanced/unbalanced head conditions.
- Seismic analysis confirmed that HFL design loads inherently accommodated earthquake- induced hydrodynamic pressures.

By harmonizing hydraulic efficiency, mechanical reliability, and material science, the Rohin Barrage Project sets a benchmark for sustainable water management infrastructure in India.

VIII. Future Aspects: Sustainable Development and Multifunctional Expansion

The Rohin Barrage, while fulfilling its core objectives of irrigation and flood control, holds immense potential for multifunctional development. By leveraging its strategic location, hydraulic infrastructure, and ecological assets, the barrage can evolve into a hub for sustainable tourism, water sports, and community engagement. Below is a detailed roadmap for future advancements:

a) Technological and Operational Upgrades

i. *Smart Automation*

- IoT Sensors: Deploy real-time monitoring systems for water quality, gate operations, and structural health.
- AI-Driven Predictive Maintenance: Use machine learning to forecast equipment failures and optimize repair schedules.

ii. *Renewable Energy Integration*

- Install solar panels on trestles and hoist houses to power gate operations and reduce carbon footprint.

b) Tourism Development

i. *Infrastructure and Amenities*

- *Viewing Decks and Walkways:*
  - ➢ Construct elevated platforms along the upstream pathway for panoramic views of the barrage and river.
  - ➢ Install interpretive signage detailing the barrage's engineering and ecological significance.
- *Visitor Center*
  - ➢ Develop an educational hub with interactive exhibits on water management, local biodiversity, and flood control mechanisms.
- *Eco-Tourism Packages*
  - ➢ Collaborate with travel agencies to offer guided tours, bird watching trails, and sunset cruises.

ii. *Cultural and Recreational Events*

- *Festivals:* Host annual events like "*Rohin Water Fest*" featuring boat races, cultural performances, and local cuisine.

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- *Heritage Trails:* Link the barrage to nearby historical sites (e.g., Gorakhnath Temple) to promote regional tourism.

c) *Water Sports and Adventure Tourism*

- *Facility Development:*
  - *Kayaking and Canoeing:* Designate calm-water zones upstream for recreational paddling.
  - *Rowing and Sailing:* Introduce rental services for rowboats and small sailboats.
  - *Fishing Zones:* Establish catch-and-release areas to attract anglers.
- *Adventure Sports:*
  - *White-Water Rafting:* Utilize regulated downstream releases during monsoon for seasonal rafting.
  - *Ziplining:* Install a zipline across the barrage for aerial views of the river and gates.

d) *Ecological and Biodiversity Initiatives*

- *Fish Ladders and Biodiversity Parks*
  - Retrofit fish ladders to support migratory species (e.g., Mahseer) and enhance river ecology.
  - Create riverside biodiversity parks with native flora to attract birds and butterflies.
- *Eco-Restoration*
  - Partner with NGOs for afforestation drives and wetland conservation.

The Rohin Barrage's future lies in transforming from a utilitarian structure into a dynamic, multifunctional asset. By integrating tourism, water sports, and ecological stewardship, it can drive socio-economic growth while preserving its core mission of water security. This vision aligns with global Sustainable Development Goals (SDGs 6, 8, and 11) and positions the barrage as a model for holistic infrastructure development in India.

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Authors Biographies



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Prof. Chaudhary has more than **325 publications** to his credits, including **250 (+)** scientific research papers indexed in SCI / SCIE / SCOPUS / ESCI / etc, **40 book**(s) / monograph(s) on mathematics (undergraduate, post graduate and research level) and several scientific as well as general articles. One of his books on Higher Education in India and Problems (recognized by K. R. Narayanan, the former President of India, 2003), and others are on different scientific and social aspects etc. He is recipient of some well-known fellowship(s) / Scholarship(s)/ award(s) including Elsevier's Mathematical Sciences Sponsorship Fund (MSSF) Award, London, U.K. (2023), Major Research Grants of the National Board of Higher Mathematics, Department of Atomic Energy, Government of India, Mumbai, India (2020), Scholarship of Clay Mathematics Institute, USA (2008), and Young Scientist Talent Prize by Sardar V.B. Patel Smarak Sansthan, India (2002). He was denied to ACCEPT two awards namely -International Research Awards on Science, Technology, and Management (2022) and International Scientist Research Awards on Engineering, Science, and Medicine (2022).Recently, he has been ranked among top **2%** most influential scientists by Stanford University, USA.

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Acknowledgments

Contributors to the research other than authors credited should be mentioned in Acknowledgments. The source of funding for the research can be included. Suppliers of resources may be mentioned along with their addresses.

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Authors can submit papers and articles in an acceptable file format: MS Word (doc, docx), LaTeX (.tex, .zip or .rar including all of your files), Adobe PDF (.pdf), rich text format (.rtf), simple text document (.txt), Open Document Text (.odt), and Apple Pages (.pages). Our professional layout editors will format the entire paper according to our official guidelines. This is one of the highlights of publishing with Global Journals—authors should not be concerned about the formatting of their paper. Global Journals accepts articles and manuscripts in every major language, be it Spanish, Chinese, Japanese, Portuguese, Russian, French, German, Dutch, Italian, Greek, or any other national language, but the title, subtitle, and abstract should be in English. This will facilitate indexing and the pre-peer review process.

The following is the official style and template developed for publication of a research paper. Authors are not required to follow this style during the submission of the paper. It is just for reference purposes.

Manuscript Style Instruction (Optional)

- Microsoft Word Document Setting Instructions.
- Font type of all text should be Swis721 Lt BT.
- Page size: 8.27" x 11'", left margin: 0.65, right margin: 0.65, bottom margin: 0.75.
- Paper title should be in one column of font size 24.
- Author name in font size of 11 in one column.
- Abstract: font size 9 with the word "Abstract" in bold italics.
- Main text: font size 10 with two justified columns.
- Two columns with equal column width of 3.38 and spacing of 0.2.
- First character must be three lines drop-capped.
- The paragraph before spacing of 1 pt and after of 0 pt.
- Line spacing of 1 pt.
- Large images must be in one column.
- The names of first main headings (Heading 1) must be in Roman font, capital letters, and font size of 10.
- The names of second main headings (Heading 2) must not include numbers and must be in italics with a font size of 10.

Structure and Format of Manuscript

The recommended size of an original research paper is under 15,000 words and review papers under 7,000 words. Research articles should be less than 10,000 words. Research papers are usually longer than review papers. Review papers are reports of significant research (typically less than 7,000 words, including tables, figures, and references)

A research paper must include:

a) A title which should be relevant to the theme of the paper.
b) A summary, known as an abstract (less than 150 words), containing the major results and conclusions.
c) Up to 10 keywords that precisely identify the paper's subject, purpose, and focus.
d) An introduction, giving fundamental background objectives.
e) Resources and techniques with sufficient complete experimental details (wherever possible by reference) to permit repetition, sources of information must be given, and numerical methods must be specified by reference.
f) Results which should be presented concisely by well-designed tables and figures.
g) Suitable statistical data should also be given.
h) All data must have been gathered with attention to numerical detail in the planning stage.

Design has been recognized to be essential to experiments for a considerable time, and the editor has decided that any paper that appears not to have adequate numerical treatments of the data will be returned unrefereed.

i) Discussion should cover implications and consequences and not just recapitulate the results; conclusions should also be summarized.
j) There should be brief acknowledgments.
k) There ought to be references in the conventional format. Global Journals recommends APA format.

Authors should carefully consider the preparation of papers to ensure that they communicate effectively. Papers are much more likely to be accepted if they are carefully designed and laid out, contain few or no errors, are summarizing, and follow instructions. They will also be published with much fewer delays than those that require much technical and editorial correction.

The Editorial Board reserves the right to make literary corrections and suggestions to improve brevity.



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It is necessary that authors take care in submitting a manuscript that is written in simple language and adheres to published guidelines.

All manuscripts submitted to Global Journals should include:

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The title page must carry an informative title that reflects the content, a running title (less than 45 characters together with spaces), names of the authors and co-authors, and the place(s) where the work was carried out.

Author details

The full postal address of any related author(s) must be specified.

Abstract

The abstract is the foundation of the research paper. It should be clear and concise and must contain the objective of the paper and inferences drawn. It is advised to not include big mathematical equations or complicated jargon.

Many researchers searching for information online will use search engines such as Google, Yahoo or others. By optimizing your paper for search engines, you will amplify the chance of someone finding it. In turn, this will make it more likely to be viewed and cited in further works. Global Journals has compiled these guidelines to facilitate you to maximize the web-friendliness of the most public part of your paper.

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A major lynchpin of research work for the writing of research papers is the keyword search, which one will employ to find both library and internet resources. Up to eleven keywords or very brief phrases have to be given to help data retrieval, mining, and indexing.

One must be persistent and creative in using keywords. An effective keyword search requires a strategy: planning of a list of possible keywords and phrases to try.

Choice of the main keywords is the first tool of writing a research paper. Research paper writing is an art. Keyword search should be as strategic as possible.

One should start brainstorming lists of potential keywords before even beginning searching. Think about the most important concepts related to research work. Ask, “What words would a source have to include to be truly valuable in a research paper?” Then consider synonyms for the important words.

It may take the discovery of only one important paper to steer in the right keyword direction because, in most databases, the keywords under which a research paper is abstracted are listed with the paper.

Numerical Methods

Numerical methods used should be transparent and, where appropriate, supported by references.

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Authors must list all the abbreviations used in the paper at the end of the paper or in a separate table before using them.

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Authors are advised to submit any mathematical equation using either MathJax, KaTeX, or LaTeX, or in a very high-quality image.

Tables, Figures, and Figure Legends

Tables: Tables should be cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g., Table 4, a self-explanatory caption, and be on a separate sheet. Authors must submit tables in an editable format and not as images. References to these tables (if any) must be mentioned accurately.

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Figures are supposed to be submitted as separate files. Always include a citation in the text for each figure using Arabic numbers, e.g., Fig. 4. Artwork must be submitted online in vector electronic form or by emailing it.

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Although low-quality images are sufficient for review purposes, print publication requires high-quality images to prevent the final product being blurred or fuzzy. Submit (possibly by e-mail) EPS (line art) or TIFF (halftone/ photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Avoid using pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings). Please give the data for figures in black and white or submit a Color Work Agreement form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

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Tips for Writing a Good Quality Science Frontier Research Paper

Techniques for writing a good quality Science Frontier Research paper:

1. Choosing the topic: In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

2. Think like evaluators: If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

3. Ask your guides: If you are having any difficulty with your research, then do not hesitate to share your difficulty with your guide (if you have one). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work, then ask your supervisor to help you with an alternative. He or she might also provide you with a list of essential readings.

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7. Revise what you wrote: When you write anything, always read it, summarize it, and then finalize it.

8. Make every effort: Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

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10. Use proper verb tense: Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

11. Pick a good study spot: Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

12. Know what you know: Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

13. Use good grammar: Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. Arrangement of information: Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

16. Multitasking in research is not good: Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

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22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.

23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

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- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.
- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- Single section and succinct.
- An outline of the job done is always written in past tense.
- Concentrate on shortening results—limit background information to a verdict or two.
- Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- Explain the value (significance) of the study.
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- Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
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Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

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This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.



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Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

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- Recommendations for detailed papers will offer supplementary suggestions.

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References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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