

Article

From Model Outputs to Planning Layers: A Planning Support Workflow for Differentiated Coastal Adaptation in Dalian, China

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Abstract

Coastal adaptation planning often focuses on keeping growth out of flood-prone areas, but in some coastal cities, business as usual growth may already avoid the most exposed locations while remaining concentrated near the shoreline. This problem is examined in Dalian, China, using the Land Use Evolution and Impact Assessment Model combined with connected bathtub flood exposure mapping at 30 m resolution. Existing model outputs are translated into planning support layers covering flood exposure, a coastal planning belt, and a proof-of-concept port-accessibility proxy, then used to classify growth constraint conflicts, define adaptation zones, and compare three scenarios under fixed demand inputs, spatial metrics, and sensitivity analysis across 75 parameter combinations. BAU growth concentrates within 5 km of the shoreline in high-suitability cells, indicating that coastal concentration rather than direct hazard exposure defines the main planning problem. Strong conservation, used here as a reused broad-constraint reference scenario rather than a newly designed coastal-adaptation scenario, compresses residential allocation closer to the shore, with a mean distance of 1.5 km compared with 3.1 km under BAU. Only selective adaptation redirects residential growth inland, increasing mean distance to 11.5 km and reducing residential allocation within the belt to 0%, while retaining more commercial allocation than strong conservation. Because the inundation input is based on a static connected-bathtub approximation rather than a validated hydrodynamic model, the flood-exposure component is interpreted as an exploratory screening layer rather than a flood prediction. Differentiated zoning offers a targeted pathway for reducing coastal residential exposure while recognizing commercial functions that may depend on port access.

Keywords: coastal adaptation zoning; planning-support systems; urban growth simulation; differentiated land-use management; sea-level rise



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1. Introduction

Coastal cities face an increasing set of difficult challenges. As sea-levels rise, coastal flooding and shoreline change intensifies. At the same time, urban growth pressures continue to seek out available, accessible and economically competitive lands. In many cases, the conflicting pressures collide and urban growth occurs in less than desirable, flood susceptible, and hazardous coastal areas. This raises difficult planning questions on how to manage potential growth within coastal urban places that are attractive for development in the near term, but that also address long-term climate risk and sea level rise.

These questions expose a persistent gap between environmental modeling and urban planning processes. Coastal risk assessments, flood models, and land-use simulations can

identify exposure, suitability, and projected development patterns, but they are less suited to assess the value-based judgments that underlie many urban growth-oriented planning decisions. For example, what should be restricted, where growth should be redirected, or how different land uses should be treated are typical planning issues largely undefined by modeling processes. As a result, from a planning perspective, model outputs often remain analytically informative but operationally incomplete. The problem is not the absence of data or modeling capacity, it is the lack of translation from model to policy, rules, priorities, and spatial decisions. This problem intensifies in coastal areas under pressure from sea level changes.

This study addresses the translational gap by looking carefully at some of the coastal planning issues in Dalian, China. Dalian is a major coastal city shaped by shoreline urbanization and port-related economic activity with acute exposure to sea-level rise and coastal flooding. Previous work (see Pang and Deal [1] for more detail) developed an integrated land use (LEAM) and static (connected-bathtub) flood-inundation modeling to project land allocation under varying flood conditions (using the Shared Socioeconomic Pathway (SSP) 2-4.5 (“Middle of the Road”) scenario adopted by the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report). That work established a modeling framework and ‘business as usual’ scenario that demonstrated urban growth patterns that shift measurably with coastal interventions. The present paper does not revisit those contributions, but uses the results to pose a distinct question: can our simulation model outputs be translated into actionable planning layers, conflict typologies, adaptation zones, and scenario-based planning policies?

Our baseline business as usual, BAU, results, summarized in Section 4, motivate a different framing. Rather than locating growth in obviously hazardous land, the model directs development toward suitable but shoreline-proximate locations that may become difficult to reverse once urbanized. This reframes the planning question from hazard exclusion to spatial differentiation within attractive coastal space.

The literature supports this shift from hazard recognition to scenario-based planning [2,3]. Coastal setback zones and coastal belts are well-established planning instruments [4–6], although current urban coastal adaptation scholarship also emphasizes that coastal responses should not be reduced to a binary choice between unrestricted growth and uniform retreat [3,7]. Coastal protection, accommodation, avoidance, and retreat represent distinct planning responses with different implications for land use [8]. At the same time, some coastal commercial land uses have locational requirements that differ fundamentally from more inland areas, especially in port cities where port accessibility and clustering remain important [9–11]. Taken together, this literature supports a planning approach that distinguishes among coastal land uses rather than treating all shoreline growth in the same way [7,8].

This paper develops a planning-support workflow for coastal areas built in four steps. First, land use simulation (LEAM) outputs are reorganized into planning-support layers including flood exposure classes, coastal planning belt, and a port-distance proxy, treated as a proof-of-concept layer. Second, those layers are overlaid with LEAM allocation results to profile where projected growth might likely occur to identify conflicts. Third, planning scenarios are generated and compared: (a) a BAU scenario; (b) a strong conservation scenario that uses a uniform intervention allocation from our previous study; and (c) a selective adaptation scenario that constrains coastal residential growth more strongly than coastal commercial growth while redirecting displaced growth toward safer receiving areas. Fourth and finally, the resulting patterns are synthesized into conflict typologies, zoning categories, and scenario comparison metrics that planners can interpret directly.

The paper contributes three planning-relevant elements. The first is an evidence hierarchy that distinguishes model-derived outputs, literature-supported proxies, and study-specific operational rules, making each translation step auditable. The second is a sensitivity-tested scenario structure that operationalizes differentiated coastal adaptation and contrasts it directly with both unrestricted growth and uniform restriction. The third is a set of conflict and zoning outputs that connect modeled growth dynamics to spatial planning categories that planners can act on.

This study deliberately builds on an existing modeling foundation rather than constructing a new predictive model. The calibrated LEAM model, the business-as-usual (BAU) allocation, and the strong conservation allocation are drawn from Pang and Deal [1] and are not re-estimated here. What is new is the planning workflow developed downstream of those outputs: it turns model outputs into planning layers, identifies where growth pressure and flood exposure overlap, defines five adaptation zones, tests a selective adaptation scenario that limits coastal housing while retaining port-proximate commercial uses, applies a spatial sensitivity analysis, and links each zone to candidate planning instruments. The methodological provenance of each analytical component is specified in Section 3. The contribution is therefore a second-order planning-analytical layer: it does not ask where the model predicts growth or exposure in general, but how planning responses should be differentiated among coastal locations that remain apparently suitable for development before urban lock-in occurs.

The paper proceeds as follows. Section 2 reviews the literature on coastal setback planning, differentiated adaptation, port-related land-use logic, and the broader translation gap between modeled outputs and planning action. Section 3 describes the methodology, including inherited model inputs, planning-layer derivation, scenario construction, and sensitivity analysis. Section 4 presents the scenario comparison, conflict classification, zoning results, and sensitivity findings. Section 5 discusses the implications of translating modeled outputs into actionable planning evidence for coastal urban growth management.

2. Literature Review

This section reviews the literature in support of the analytical structure of the presented study. It addresses literature relevant to the design of spatially differentiated coastal adaptation scenarios within a land use modeling framework: coastal adaptation, differentiated adaptation, and scenario planning and downweighting.

2.1. Coastal Adaptation

For clarity, this paper distinguishes four related terms. Coastal adaptation refers to the overall objective of adjusting development to sea-level rise and flood exposure; coastal management refers to the broader governance of coastal land uses; coastal planning refers to the forward-looking process of guiding where and how growth occurs; and coastal zoning refers to the spatial instrument through which planning intentions are expressed as differentiated land-use categories. The workflow presented here is a planning-support tool whose output is a zoning-style framework serving coastal adaptation objectives.

Coastal adaptation is increasingly framed not only as a hazard management problem but also as a land use and spatial planning problem [3,7,12–15]. Recent adaptation literature emphasizes that responses to sea-level rise and coastal flooding extend beyond structural protection [8,16] and include avoidance [2,4,5,17], accommodation [6,8], retreat [3,7,18], and advance [8,19], each implying different land use decisions and different relationships between development and risk [8,20]. Haasnoot et al. [3] further argue that managed retreat should be understood as a multidecadal pathway that begins well before physical relocation, including vulnerability assessment, land use planning, no-build zones, and the

identification of alternative development locations. Within the protection response itself, recent work has moved beyond traditional gray structures toward nature-based, hybrid gray–green, and multifunctional coastal protection approaches that combine engineered defense with ecological and co-benefit functions [21,22].

Coastal adaptation strategies include the use of a coastal planning belt [17,19]. At the policy level, coastal setbacks are recognized planning instruments in multiple jurisdictions [2,17]. Rochette et al. [4] identify the Mediterranean ICZM Protocol as the first multilateral legal instrument prescribing a minimum coastal setback, thereby establishing setbacks as a formal planning tool rather than an informal guideline. Simpson et al. [5] and Zhu et al. [6] show that setback distances vary widely in practice, ranging from tens of meters to much broader locally calibrated zones, and that many jurisdictions now rely on site-specific criteria such as erosion rates, coastal dynamics, or extreme water levels rather than one fixed universal distance.

Recent work demonstrates that setback zones can be embedded directly into spatial growth models. Wolff et al. [2] incorporated multiple distance-based and elevation-based setback scenarios into a European urban change model to show that setback policies can substantially reduce the exposure of new development to sea-level rise. Their study is methodologically important because it provides a precedent for sensitivity testing across alternative setback definitions rather than assuming a single predetermined threshold. In the Chinese context, Lau [23] similarly used multiple shoreline-distance belts to analyze the coastal zone, explicitly noting that no single consistent definition of the Chinese coastal zone exists. Zhang and Ning [24] further show that the 0–10 km coastal band in China has the highest land-use development intensity and the most pronounced ecological land loss, reinforcing the importance of shoreline-proximate development space as a distinct planning concern.

2.2. Differentiated Adaptation

The literature supports distinguishing among adaptation approaches rather than treating all coastal growth spaces identically. Cooley et al. [8] define an approach that uses land-use planning and asset modification to reduce vulnerability while allowing continued occupancy in at-risk areas. Mach and Siders [7] argue that managed retreat should be reframed as a proactive and transformative adaptation strategy rather than a simple sign of planning failure. They emphasize that different assets have different operational, social, and economic logic, and therefore warrant different treatment. A key implication of differentiated adaptation is that residential and commercial land should not automatically receive the same planning treatment [3,7]. For example, Notteboom et al. [9] describe seaports as places of functional and spatial clustering, where logistics, industrial, and commercial activities concentrate to capture scale and scope advantages. Empirical studies confirm that port access is among the most important determinants of logistical location, ranking second only to land cost [11], although proximity to highways, airports, seaports, and major urban markets remain important locational requirements [10]. The clustering logic is reinforced by agglomeration economies and self-reinforcing spatial advantages, meaning that even small locational benefits can sustain disproportionate concentration in port-related areas. Heitz et al. [25] document this pattern in Gothenburg, SE, where over half of all regional warehouse facilities are concentrated in port-adjacent areas despite ongoing sprawl. The literature also notes port regionalization, in which some logistics and distribution functions extend inland along major corridors rather than remaining immediately adjacent to the port [9,26].

2.3. Scenario Planning and Downweighting

Some scholars trace the origin of scenario planning to big oil conglomerates in the 1950's [27,28] and later to transportation planning in the 1960's [29]. It is typically used to consider multiple aspects of a problem simultaneously to aid in decision making [30–32]. Business and military interests connected scenario planning to assessing 'interactive causal relationships' between external influences—such as environmental, political, or economic conditions—and a range of possible action strategies. The use of scenarios for metropolitan planning is thought to have been pioneered in Portland, OR, US in the early 1990s [33]. Hopkins and Zapata [34] found that scenario analysis at the metropolitan scale is typically focused on developing a single preferred vision, while Chakraborty et al. [30] advance robust and contingent strategies that more effectively incorporate uncertainty for long-term planning.

The scenario structure in this paper uses downweighting to reduce development competitiveness in selected spaces. Downweighting scales back the probability of growth by reducing attractiveness variables in a land use change simulation. This provides a useful planning analog for selective adaptation scenarios in which concerning areas are not removed from development entirely but are made less competitive. This is conceptually supported by evidence from Hashida and Dundas [12]. They describe the U.S. Coastal Barrier Resources Act (CBRA), which operates not by prohibiting development directly but by withdrawing federal financial assistance and thereby lowering development viability. Druckenmiller et al. [18] found that CBRS-designated areas have approximately 83% fewer buildings per acre than comparable undesignated coastal lands, indicating that reducing incentives can be a growth deterrent.

We found no universal standards for the exact spatial width of a coastal belt or the exact multiplier values used to represent planning discouragement in the literature we reviewed. The coastal adaptation and setback literature justifies testing multiple widths rather than assuming one correct value [2,5,6,23]. The same logic applies to growth weight multipliers. No standard source prescribes a single residential down weight or commercial preserve multiplier for spatial growth models, so these values must be treated as study-specific scenario variables rather than literature-derived constants. The 5 km belt used in the main scenario is justified as a tested planning-support proxy rather than a statutory setback or geomorphological threshold. First, the coastal-adaptation literature does not prescribe a universal belt width, which motivates testing a range rather than assuming a single fixed value. Second, the sensitivity analysis (Table S2) reveals a belt-width plateau: allocation outcomes are identical for belt widths of 5, 7, and 10 km, whereas narrower belts of 2–3 km leave part of the shoreline-proximate growth concentration outside the belt. The 5 km width is therefore the smallest tested belt that fully encloses the BAU coastal growth concentration; widening it further captures no additional constrained growth. Third, in Dalian, this width approximates the functional coastal–urban interface where shoreline proximity, flood exposure, and port-related development pressure co-occur, as reflected in the spatial concentration of growth-constraint conflict along the southern port-urban coastline (Section 4.4).

3. Materials and Methods

This study develops a coastal planning-support system (PSS) framework for Dalian, China (Figure 1) using existing modeled outputs from an integrated LEAM and connected-bathtub flood-inundation study by Pang and Deal [1]. The calibrated model, BAU allocation, and strong conservation allocation are taken from that study and are not re-estimated here; they are summarized only to the extent needed to interpret the workflow developed in this paper. The present contribution is the downstream translation workflow, which reor-

ganizes those outputs into planning-support layers, growth-constraint conflict typologies, adaptation strategy zones, literature-grounded planning scenarios, spatial sensitivity tests, and planner-facing metrics.

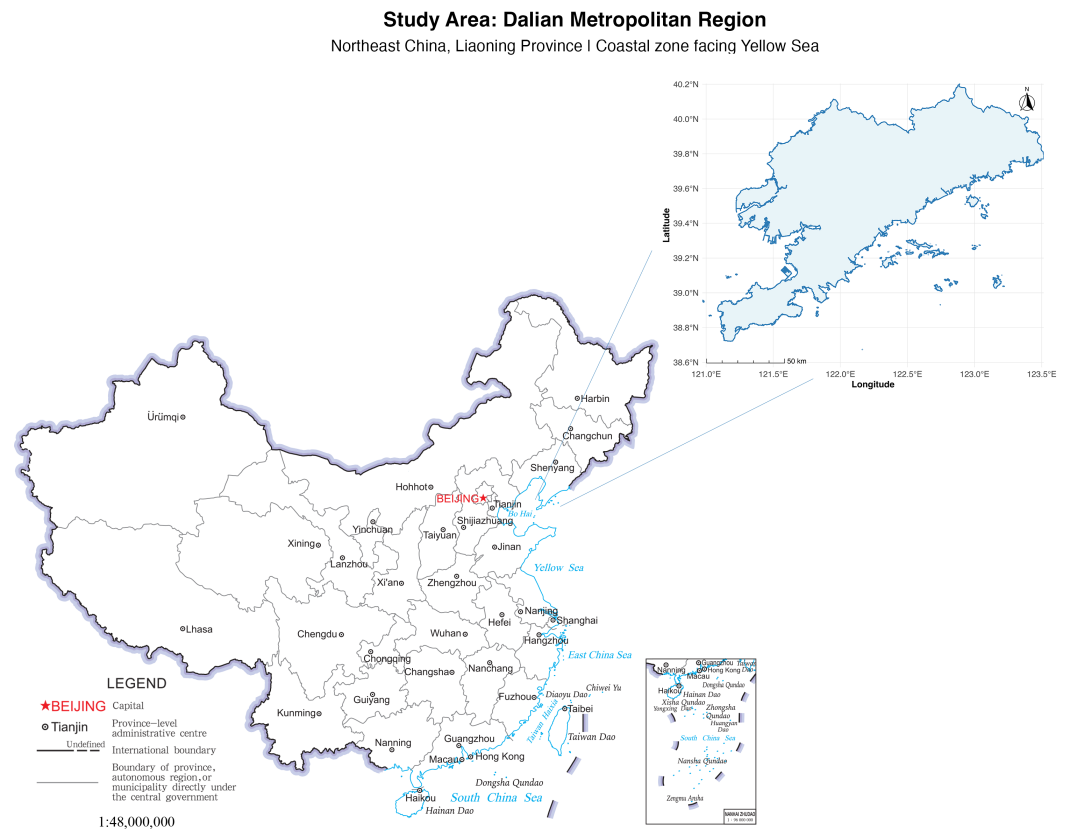


Figure 1. Study area location. The Dalian Metropolitan Region in Liaoning Province, Northeast China, encompasses approximately 13,400 km² of coastal territory facing the Yellow Sea. The region includes urban cores, peri-urban development zones, and rural hinterlands subject to sea level rise and coastal flood hazards. Figure prepared by the authors using spatial data described in Section 3 and adapted from Pang and Deal [1].

The translation workflow is summarized in four phases (Figure 2). Phase 1 identifies the model outputs drawn from our previous LEAM modeling study [1]. Phase 2 derives planning-support layers from those outputs and overlays them with our BAU allocation result to classify growth-constraint conflicts and define adaptation zones. Phase 3 constructs planning scenarios and compares them using both count-based and spatial redistribution metrics. Phase 4 generates spatial maps, conflict typologies, scenario comparison figures, and sensitivity tables outlining potential development zones.

Throughout the analysis, three levels of evidentiary status are distinguished. Level 1 components are model-derived and come directly from the calibrated LEAM and connected-bathtub flood-inundation pipeline established in the paper by Pang and Deal [1]. Level 2 components are literature-supported proxies, meaning that their conceptual basis is grounded in published coastal adaptation and planning research, but their specific parameterization is study-specific. Level 3 components are study-specific operationalizations, including scenario rules and thresholds that are treated as testable assumptions rather than literature-prescribed standards and are therefore subjected to sensitivity analysis.

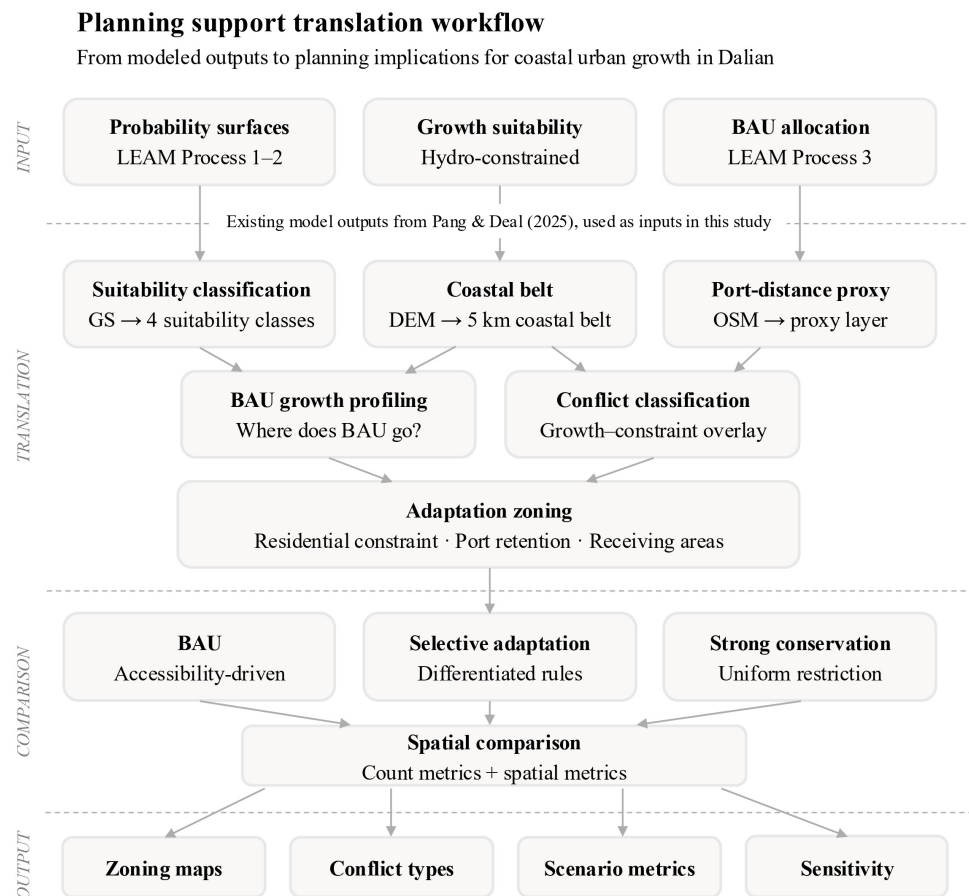


Figure 2. Planning support translation workflow. The workflow proceeds in four phases, from LEAM and flood-inundation model outputs drawn from Pang and Deal [1] (input) through planning layer derivation and conflict classification (translation) to scenario construction and comparison (comparison), producing zoning maps, conflict typologies, scenario metrics, and sensitivity results (output) for coastal urban growth management in Dalian, China.

3.1. Phase 1: Model Inputs

Raster-based spatial data outputs from Pang and Deal [1] serve as inputs to the present analysis. These outputs were not modified and entered the planning-support workflow exactly as produced by the original modeling pipeline. See Table 1 for a summary.

Probability surfaces (Level 1) were generated through the LEAM modeling process using ridge logistic regression, fitted to observed 2016 land use patterns with OSM-informed attraction maps as predictors. Three probability surfaces are used here: urban residential (AUC = 0.977), urban commercial (AUC = 0.962), and cropland (AUC = 0.740), as reported in Pang and Deal [1]. These surfaces represent the spatially varying likelihood that each 30 m cell will be selected for a given land use, conditional on accessibility to employment, transportation, population, and environmental amenities.

The growth suitability surface (Level 1) integrates the 2050 SSP2-4.5 sea-level-rise projections [35], converted to flood exposure through a connected-bathtub model that identifies inundated cells using 8-connectivity to the coastline and applies a 5 m elevation clip. The 5 m cutoff was used as an upper-bound screening threshold to restrict the connected-bathtub procedure to low-lying, coastline-connected terrain. This threshold is consistent with the elevation-band logic used in low-elevation coastal-zone screening, commonly defined as contiguous coastal land below 10 m elevation [36], while remaining well above the sub-meter mean sea-level rise projected for 2050 under SSP2-4.5. Values range from 0—indicating full inundation (and development exclusion), to

1—indicating minimal flood exposure (and full developability). This surface encodes both flood exposure and policy constraints, including permanent farmland protection and ecological conservation zones, as continuous suitability scores. For the present analysis, the growth suitability (GS) surface is reclassified into four discrete suitability classes: Class 1 ($GS \leq 0.2$, very low suitability/high constraint), Class 2 ($0.2 < GS \leq 0.4$, low suitability), Class 3 ($0.4 < GS \leq 0.7$, moderate suitability), and Class 4 ($GS > 0.7$, high suitability). Because the growth-suitability surface integrates flood exposure together with policy constraints and development conditions, these bins represent composite development suitability rather than isolated flood risk. We therefore refer to them as suitability classes rather than flood-risk classes.

Allocation outputs (Level 1) were produced in LEAM by matching economic demand projections to spatially suitable locations through a competitive selection algorithm. For each cell and land use type, the composite allocation score is the multiplicative product of probability, growth suitability, the developability mask, and the tier-based growth weight, where tiers represent ordinal developability classes (Tier 0 = protected, Tier 1 = restricted, Tier 2 = conditionally developable) taken from Pang and Deal [1]. The highest-scoring cells are allocated until demand is met. Two allocation rasters are taken from our previous BAU scenario—accessibility driven growth under standard policy constraints, and the intervention allocation from Pang and Deal [1] representing growth under uniform wetland protection and blue-green corridor constraints. Both scenarios use the same demand assumptions, but allocation outcomes differ because spatial constraints affect whether and where demand can be accommodated. Consistent with this rationale, the coastal belt is treated as a planning-support proxy evaluated across multiple widths, not as a regulatory setback line. The 5 km main value is the smallest tested width at which allocation outcomes plateau (identical results at 5, 7, and 10 km; Table S2), so it fully encloses the shoreline-proximate growth concentration without over-extending the belt.

Table 1. Evidence status and methodological role of planning-support components. Summary of the six analytical components used in this study, classified by evidence status. Each component is described with its data source, planning function, and implications for how it should be interpreted in the methods and results.

Component	Evidence Level	Description and Data Source	Methodological Implication
Growth suitability	model-derived	GS-based suitability classes derived from the bathtub-derived flood-exposure surface.	Primary modeled suitability layer; threshold sensitivity documented.
Coastal belt	planning-support proxy	Shoreline-distance belt derived from DEM/ocean adjacency; used as a coastal planning proxy rather than a universal regulatory boundary.	Parameterized belt width treated as a Level 2 study-specific operationalization and evaluated through sensitivity analysis across multiple widths.
Port distance	proof-of-concept proxy	OSM-derived distance to major identified port anchors; used as a proof-of-concept proxy rather than a comprehensive port inventory.	Supports differentiated commercial treatment as an illustrative proxy; not a definitive port-accessibility or logistics surface.
BAU allocation	model-derived	Reference allocation from the existing LEAM + bathtub flood-exposure workflow (Pang & Deal [1]).	Baseline comparator; no modification.
Strong conservation	scenario operationalization	Broad conservation constraint scenario reusing the earlier wetland protection and blue-green corridor intervention allocation (wetland protection 810 km ² + blue-green corridors 8 km ²); no new model run performed beyond Pang & Deal [1].	Pang & Deal [1] intervention reinterpreted as a broad conservation constraint benchmark; provenance must be stated explicitly.
Selective adaptation v2	scenario operationalization	Differentiated scenario that constrains coastal residential growth more strongly while allowing conditional retention of port-proximate commercial growth.	Literature-grounded planning scenario with study-specific parameters; sensitivity-tested.

3.2. Phase 2: Planning Layer Derivation and Conflict Classification

This phase derives supplementary planning layers not present in the existing model outputs. These include a coastal planning belt, port distance proxy, and a business as usual growth profile. These are integrated to produce a growth constraining, conflict classification, and adaptation zoning framework. **Coastal planning belt.** Because Dalian is exposed to the sea on three sides, the distance of projected growth to the shoreline is a primary planning concern. A continuous distance-to-coast surface was derived from the SRTM-based DEM [37] and ocean adjacency mask already used in the bathtub flood-inundation work. From this surface, a coastal planning belt was defined as all land cells within a specified distance of the shoreline. The default belt width was set at 5 km, a parameterization motivated by the BAU profiling analysis described below and tested through sensitivity analysis (Section 3.3). This threshold falls within the range of Chinese coastal zone planning distance bands documented in the literature [23,24], but is a study-specific parameterization that is evaluated through sensitivity analysis.

Port-distance proxy. To support differentiated treatment of coastal commercial growth, a distance-to-port layer was derived from polygon features extracted from OpenStreetMap (OSM). OSM coverage in China has been validated as adequate for urban land-use research [38]. Port features were extracted from OSM and compiled by the authors into an OSM land-use geodatabase for the study area. Port polygons were converted to centroids, and Euclidean distance to the nearest centroid was calculated for each raster cell. The principle of distinguishing port-proximate commercial land from residential land is supported by the economic geography and port logistics literature [9–11]. The OSM-derived port layer captures major southern coastal port anchors available in the dataset and is therefore interpreted as proof-of-concept support for differentiated commercial treatment rather than a definitive accessibility surface.

BAU growth profiling. Before constructing alternative planning scenarios, the BAU allocation was profiled spatially by cross tabulating allocated cells across suitability class, planning tier, coastal belt membership, and distance to port. This diagnostic step characterizes where modeled growth concentrates and identifies the spatial bands within which differentiated rules can meaningfully alter outcomes. The diagnostic outputs are reported in Section 4 and directly informed the parameterization of the selective adaptation scenario described below.

Growth-constraint and Adaptation Zoning. The BAU results were integrated with planning layers to produce a typology map. The background includes all cells outside the coastal belt or with low urban development pressure. The coastal BAU-prone growth space identifies cells within the coastal belt where urban pressure, defined as the maximum of residential and commercial probability, exceeds the 75th percentile. Hydrologically constrained coastal growth space identifies a subset of cells representing coastal growth space with transitional flood exposure. BAU-selected urban in the coastal belt marks cells where the BAU allocation is placed for residential or commercial growth within the belt. This classification provides the spatial basis for adaptation zoning.

A five-zone adaptation typology was derived from the conflict classification, planning layers, and BAU profiling results. Zone 1, the coastal residential constraint zone, identifies coastal belt cells with residential probability above the 75th percentile, where residential growth is downweighted under the selective adaptation scenario. Zone 2, the port-commercial conditional retention zone, identifies coastal belt cells within 5 km of a port anchor where commercial probability exceeds the 75th percentile; commercial growth is treated more permissively than residential growth. Zone 3, the safer receiving area, identifies non-BAU Tier 2 cells in Suitability Class 4 outside the coastal belt with high urban pressure, where redirected growth is preferentially received. Zone 4, the residual

coastal belt outside Zones 1–2, identifies the remaining portion of the 5 km coastal belt after the targeted residential constraint and port-commercial conditional retention zones are excluded. Zone 5 is the background zone comprising all remaining cells. The relatively small areas of Zones 2 and 3 reflect their function as targeted planning instruments rather than balanced land classifications.

3.3. Phase 3: Scenario Construction and Comparison

Three planning scenarios were constructed to compare different adaptation postures for coastal urban growth (Table 2). All three scenarios use the same fixed demand inputs derived from BAU. Allocation outcomes differ because spatial constraints and weighting rules affect whether and where that demand can be accommodated. This fixed-demand design ensures that scenario differences reflect spatial constraints and allocation outcomes under the same projected growth pressure, rather than changes in projected demand.

Table 2. Scenario design. Three scenarios are compared in this study. Only selective adaptation required a new model run. Business as usual and strong conservation reuse allocation outputs from Pang and Deal [1].

Scenario	New Model Run	Adaptation Posture	Key Parameters	Provenance
Business as usual	No	Accessibility-driven coastal concentration	Unmodified LEAM Process 3 allocation under SSP2-4.5 demand and flood suitability.	Baseline allocation from Pang and Deal [1].
Strong conservation	No	Broad conservation constraint	Wetland protection (810 km ²) and blue–green corridor constraints applied as Tier 0 and Tier 1 reclassification.	Intervention allocation from Pang and Deal [1], reinterpreted as a broad conservation constraint scenario.
Selective adaptation	Yes	Differentiated coastal management	Residential downweight (0.50) in 5 km coastal belt; commercial downweight (0.90) with port restoration (1.00 within 5 km of port); receiving-area upweight (residential 1.20, commercial 1.05).	New allocation generated in the present study.

Note: All three scenarios use the same fixed demand inputs derived from SSP2-4.5 sectoral employment projections: 4567 residential cells, 3687 commercial cells, and 8946 cropland cells. Differences across scenarios therefore reflect spatial constraints and weighting rules applied to the allocation surface, not changes in projected demand. Because constraints can limit available suitable cells, using the same demand inputs does not imply that all demand is fully allocated in every scenario. Under BAU, 3541 of 3687 commercial demand cells (96.0%) are allocated, indicating that a small share of projected commercial demand remains unmet even in the baseline allocation.

As noted, the BAU scenario uses the allocation output from previous work without modification. It represents accessibility-driven growth under standard policy constraints and 2050 SSP2-4.5 flood suitability. No new model run was performed. The existing raster is reinterpreted here as the reference planning scenario.

Strong conservation. The strong conservation scenario reuses the intervention allocation output from Pang and Deal [1], which implemented wetland protection and blue–green corridor constraints. Here, it is reinterpreted as a broad conservation constraint benchmark rather than a newly designed coastal restriction scenario. No new model run was performed for this paper. This provenance is made explicit because the planning-support question in the present paper concerns where growth goes under broad conservation constraint, not whether that intervention raster was newly generated.

Selective adaptation. The selective adaptation scenario operationalizes a differentiated planning posture in which coastal residential growth is constrained more strongly than coastal commercial growth, while port-proximate commercial development receives conditional retention.

Residential cells within the coastal belt receive a multiplicative factor of 0.50, reducing their composite allocation score by half. Residential cells in the receiving area receive a factor of 1.20, modestly increasing their competitiveness. Commercial cells within the coastal belt receive a factor of 0.90, but cells within 5 km of a port anchor are restored to a factor of 1.00, which overrides the belt-wide reduction. Commercial cells in the receiving area receive a factor of 1.05. Cropland remains unchanged with a factor of 1.0 throughout.

These multiplier values are illustrative planning operationalizations rather than empirically calibrated constants. As noted in Section 2.3, the literature provides planning principles rather than model-specific multiplier values, so the values were selected to express a directional planning logic rather than a precise magnitude: residential growth within the belt is halved (0.50) to represent strong discouragement; commercial growth is only mildly discouraged (0.90) and restored to 1.00 within 5 km of a port anchor to reflect the functional coastal dependence of port-related activity; and receiving areas are modestly upweighted (residential 1.20, commercial 1.05) to redirect rather than eliminate displaced demand. The asymmetry between the residential and commercial factors, not their exact values, carries the planning meaning. The downweighting mechanism is grounded in real planning instruments that lower development viability without outright prohibition, such as the withdrawal of federal assistance under the U.S. Coastal Barrier Resources Act [12,18]. The sensitivity analysis, reported in Section 4, evaluates robustness to these choices by sweeping residential response (mild, medium, strong), commercial response (none through strong), and belt width (2–10 km).

The modified composite scores are then processed through the same competitive allocation algorithm used in LEAM Process 3, the final land allocation step in Pang and Deal [1]. Cells are ranked by score within each land-use category, and the highest-scoring cells receive allocation up to the demand threshold. Selective adaptation therefore differs from BAU only in the spatial weighting that reshapes competitiveness within the coastal zone.

Comparison metrics and sensitivity analysis. Scenario comparison uses count-based metrics to report the total number of allocated cells by land use, suitability class, and coastal belt membership. These metrics capture how much growth occurs in each category. Spatial metrics report where growth is placed, including the fraction of residential cells inside the coastal belt, the mean and median distance of residential cells to the shoreline, and the fraction of commercial cells within 5 km of a port anchor.

Spatial metrics are included alongside count-based metrics because residential demand can, in principle, be satisfied at very different locations across scenarios. When scenarios differ primarily in placement rather than total allocation, count-based metrics alone cannot distinguish the differences.

A systematic sensitivity analysis was conducted across a grid of belt-width, residential response, and commercial-response combinations. Belt widths of 2, 3, 5, 7, and 10 km were tested. Residential response levels included mild, medium, and strong downweighting. Commercial response levels included none, very light, light, moderate, and strong downweighting. Port band and receiving rule were held constant at their main-scenario values. The exact multiplier corresponding to each qualitative response level is reported in Table S1, and the complete set of 75 parameter combinations with their key outputs is provided in Table S2.

Each parameter combination produced a complete allocation, from which we extracted total urban cells, residential and commercial cells, urban cells by suitability class, residential coastal share, residential mean distance to coast, commercial coastal share, and commercial port near share. The sensitivity analysis serves to test the robustness of the selective adaptation outcome across alternative parameter combinations rather than at a single chosen setting. It also characterizes how the allocation system responds to changes in

residential downweighting and evaluates the sensitivity of outcomes to belt width across the tested range.

3.4. Data Sources and Software

Land use classification derives from the China Multi Period Land Use Remote Sensing Monitoring Dataset at 30 m resolution (Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, China). Elevation data use the 30 m SRTM DEM (NASA Jet Propulsion Laboratory, Pasadena, CA, USA). Population grids use the ASPECT dataset (Accurate and Spatially Explicit Continental-scale Estimates of Total population; Nanjing University, Nanjing, China) at 100 m resolution, aggregated to study area resolution. Transportation and port features derive from OpenStreetMap (OpenStreetMap Foundation, UK), with administrative boundaries from Tianditu [39]. Bathymetry uses the GEBCO grid. Sea level projections follow the SSP2-4.5 pathway based on IPCC AR6 regional assessments for the Northwest Pacific [35]. All data sources and processing steps are described in detail in Pang and Deal [1]. All raster operations were conducted in R (v4.5.2) using the terra package (v1.8.60) with 30 m resolution aligned to a common template. Spatial vector operations used sf (v1.0.20) [40]. Table processing used dplyr (v1.1.4) [41] and readr (v2.1.5) [42]. Figure generation used ggplot2 (v3.5.2) [43]. The full analysis workflow, including the selective adaptation allocation script and the final planning support synthesis scripts, is available from the corresponding author upon request.

4. Results

The scenarios produced clearly different allocation outcomes (Table 3). BAU allocates 8108 urban cells, including 4567 residential and 3541 commercial cells. Strong conservation, which reuses the intervention allocation from Pang and Deal [1] as a reference point rather than a newly designed coastal-adaptation scenario, is the most restrictive scenario, reducing total urban allocation to 4575 cells by suppressing commercial growth from 3541 to 8 cells while leaving residential demand fully satisfied at 4567 cells. Selective adaptation occupies an intermediate position between these two extremes: it preserves the full residential allocation of 4567 cells while retaining 2360 commercial cells, producing a total urban allocation of 6927 cells—below business as usual but above strong conservation.

This pattern confirms that the selective adaptation scenario functions as a middle scenario. The main spatial effect is not residential volume reduction but the redirection of residential growth away from the coastal belt while allowing partial retention of commercial growth near port areas.

4.1. BAU Growth Profiling Reveals a Coastal Concentration Problem Rather than a Simple Hazard-Avoidance Problem

The BAU allocation concentrated urban growth in the most developable and least constrained spaces available. Nearly all BAU urban cells (97.7%) fall in Tier 2 and Suitability Class 4, with only 185 cells (2.3%) lower-suitability classes, indicating that the LEAM and flood-exposure suitability workflow filters out the most constrained or hazardous land upstream. These suitability patterns should be interpreted in light of the exploratory nature of the underlying flood-exposure layer. Because the layer is based on a static connected-bathtub approximation rather than a validated hydrodynamic model, the suitability classes indicate relative exposure and development constraint rather than modeled inundation probability or dynamic flood behavior.

Growth is strongly coastal. Both residential and commercial allocations are fully contained within the 5 km coastal belt, with residential cells averaging 3.06 km from the shoreline and commercial cells clustering closer to the coast. These results shift the planning

question from a simple inland versus coastal distinction toward how growth management can be differentiated within seemingly suitable but shoreline proximate urban space.

Sensitivity analysis across belt widths of 2 to 10 km confirms this empirically. Results plateau at 5 km, indicating that the 5 km belt captures the full set of BAU coastal cells and provides an empirically grounded default rather than an arbitrary setback distance (Figure 3).

Table 3. Scenario comparison metrics. Count-based and spatial metrics for the three planning scenarios. Residential demand is fully allocated in all scenarios (4567 cells), so residential differences reflect spatial redistribution. Commercial allocation differs across scenarios and includes suppressed allocation relative to BAU. Cropland allocation (8946 cells) is identical across scenarios and omitted for clarity.

Metric	Business as Usual	Selective Adaptation	Strong Conservation
Count-based metrics			
Urban total (cells)	8108	6927	4575
Residential allocated (cells)	4567	4567	4567
Residential unmet demand (cells)	0	0	0
Commercial allocated (cells)	3541	2360	8
Commercial suppressed allocation vs BAU (cells, %)	0 (reference)	1181 (−33.4%)	3533 (−99.8%)
Spatial metrics (residential)			
Residential coastal share (%)	100	0	100
Residential mean distance to coast (km)	3.06	11.49	1.45
Residential median distance to coast (km)	3.64	5.53	1.30
Spatial metrics (commercial)			
Commercial coastal share (%)	100	100	100
Commercial mean distance to coast (km)	1.57	0.56	0.79

Note: Coastal share is the fraction of allocated cells within the 5 km coastal belt. Residential demand is fully allocated in all scenarios; therefore, residential differences reflect spatial redistribution rather than unmet demand. Commercial suppressed allocation is calculated relative to the BAU commercial allocation of 3541 cells. These values indicate commercial growth that is not allocated under stronger coastal constraints, rather than growth simply relocated elsewhere. Commercial port proximity is treated as a supplementary diagnostic because the OSM-derived port layer represents formal port features rather than the broader port-related industrial–commercial district; it is not reported in this table. Cell size is 30 m × 30 m (0.09 ha).

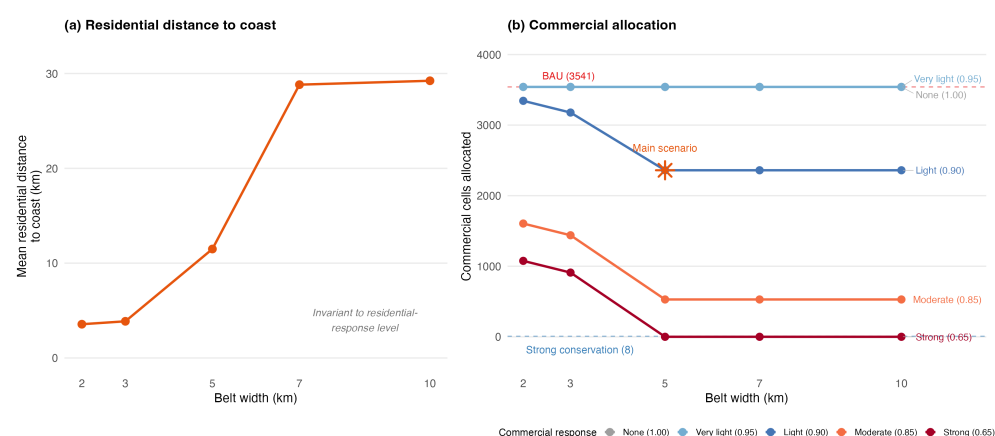


Figure 3. Sensitivity of selective-adaptation outcomes to coastal-belt width and response level. (a) Mean residential distance to coast, which varies by belt width but is invariant to residential-response level. (b) Commercial cells allocated by belt width and commercial-response level; the star marks the main scenario (5 km belt, light commercial response). Dashed horizontal lines indicate the BAU (3541 cells) and strong-conservation (8 cells) benchmarks. The panels show contrasting behavior: housing relocation follows a threshold response, with coastal residential share falling to 0% across all 75 combinations (Table S2), whereas commercial allocation varies with both response strength and belt width, declining from the BAU level toward zero under stronger downweighting and wider belts.

This 0% coastal share is a threshold response of the rank-order allocation rather than a gradual decline: any residential downweight large enough to push coastal cells below the next-ranked inland alternatives removes them from the belt entirely, so the share is 0% across all tested residential levels and belt widths (Table S2). Commercial allocation, by contrast, responds continuously to the commercial multiplier, declining from 3541 cells (no downweight) to 0 under the strongest setting at belt widths of 5 km or more.

4.2. Selective Adaptation Primarily Changes Residential Location Rather than Residential Quantity

Scenario differences operate through two mechanisms: spatial redistribution and suppressed allocation. Residential demand is fully satisfied in every scenario (4567 cells), so residential differences reflect spatial redistribution alone, with no unmet residential demand. Commercial allocation, by contrast, is partly suppressed relative to BAU. Compared with 3541 commercial cells allocated under BAU, selective adaptation allocates 2360 commercial cells, a reduction of 1181 cells (−33.4%), while strong conservation allocates only 8 commercial cells, a reduction of 3533 cells (−99.8%). These reductions represent commercial growth that is not allocated under stronger coastal constraints, rather than growth simply relocated elsewhere.

Count-based metrics alone understate the effect of residential rules because residential demand is fully satisfied under all three scenarios. Spatial metrics reveal the substantive effect. Under BAU, 100% of residential cells fall within the coastal belt. Under selective adaptation, the residential coastal share drops to 0%, and the mean distance of residential cells to the shoreline increases from approximately 3.06 km to approximately 11.49 km. By contrast, strong conservation retains all residential allocation within the coastal belt, with a mean residential distance to coast of approximately 1.45 km (median 1.30 km), closer to the shoreline than BAU (mean 3.06 km, median 3.64 km). This counterintuitive result is a re-ranking effect within the allocated set rather than a corridor-exclusion effect on the eligible pool. A diagnostic check confirms that the wetland and blue–green corridor masks do not remove any BAU coastal-belt residential cells from the eligible pool, and that the eligible pool’s mean distance to coast is essentially unchanged across scenarios (2.09 km for BAU, 2.14 km for strong conservation). The shift therefore originates in the composite score, not in eligibility. Because the prior intervention weighting alters the tier-based growth weights that enter the composite allocation score, it appears to lower the relative competitiveness of some inland eligible cells; near-shore eligible cells consequently rise in the rank-order allocation and are selected first, even though they were equally available under BAU. In other words, conservation constraints redistribute which eligible cells win the top-ranked residential slots rather than which cells are eligible, and under the prior weighting, the selected cells are more shoreward. The full distance-to-coast distribution of allocated residential cells across scenarios is shown in Figure S1. A complete decomposition of the prior scoring choices is beyond the scope of the present paper, since strong conservation is reused here only as a broad conservation-constraint benchmark [1], while the focal contribution is the selective adaptation workflow and its planning interpretation (Figure 4).

These results suggest that residential downweighting acts as a spatial redirection mechanism rather than a volumetric control. Because LEAM allocates cells by rank order of composite score, the multiplier shifts coastal residential cells below the next-ranked inland alternatives in the composite score distribution, producing a threshold response rather than a gradual decline in coastal share.

Residential spatial redistribution across scenarios
n = 4567 residential cells in each scenario

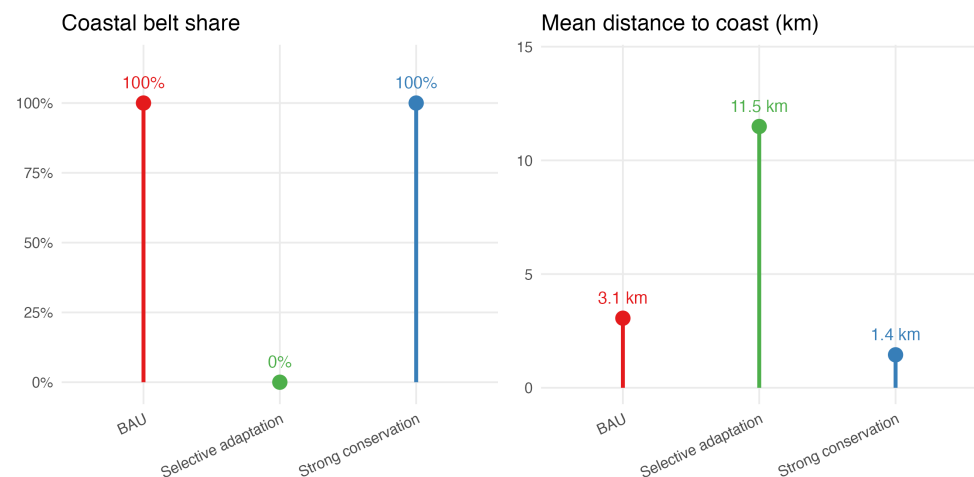


Figure 4. Residential spatial redistribution across scenarios. Coastal belt share (**left**) and mean distance to coast (**right**) for 4567 residential cells under each scenario. BAU and strong conservation retain 100% of residential cells within the coastal belt (mean 3.1 km and 1.5 km respectively). Selective adaptation redirects all residential cells outside the belt (mean 11.49 km).

4.3. Commercial Allocation Is the Main Quantitative Differentiator Across Scenarios

Commercial allocation responds much more strongly than residential allocation to scenario rules. BAU allocates 3541 commercial cells, selective adaptation retains 2360 (a 33% reduction), and strong conservation reduces commercial allocation to 8 cells (a 99.8% reduction). This establishes commercial treatment as the principal quantitative lever separating the three scenarios.

The commercial results support the logic of conditional retention rather than uniform exclusion. The OSM-derived port distance layer is interpreted conservatively as a supplementary proxy, not as a complete representation of Dalian's port economic geography.

4.4. Growth-Constraint Conflicts Concentrate Along the Coastal Belt and in the Southern Port District

The conflict classification identifies a spatially concentrated planning problem rather than a diffuse regional pattern. Conflict is highest where BAU-prone urban growth overlaps the coastal belt and where flood-exposure constraint intersects with shoreline proximate development pressure. This pattern is especially visible in the southern urban port area, where coastal accessibility, port-related commercial relevance, and shoreline constraint converge (Figure 5).

4.5. Adaptation Zoning Produces a Targeted Rather than Uniform Planning Framework

The adaptation zoning map (Figure 6) translates model outputs and conflict results into a rule-based planning framework with five zones (Table 4). The coastal residential constraint zone (1789 km², 13.4%) and the residual coastal belt outside Zones 1–2 (3221 km², 24.1%) occupy the largest shares of designated intervention space, while the port-commercial conditional retention zone (83 km², 0.6%) and safer receiving area (906 km², 6.8%) remain comparatively limited and targeted. The remaining 7391 km² (55.2%) falls outside designated planning zones. This distribution is not a weakness of the zoning system; rather, it reflects the underlying allocation geography. Most BAU-prone growth is concentrated in coastal space, while only a smaller subset meets the criteria for conditional commercial retention or inland receiving capacity.

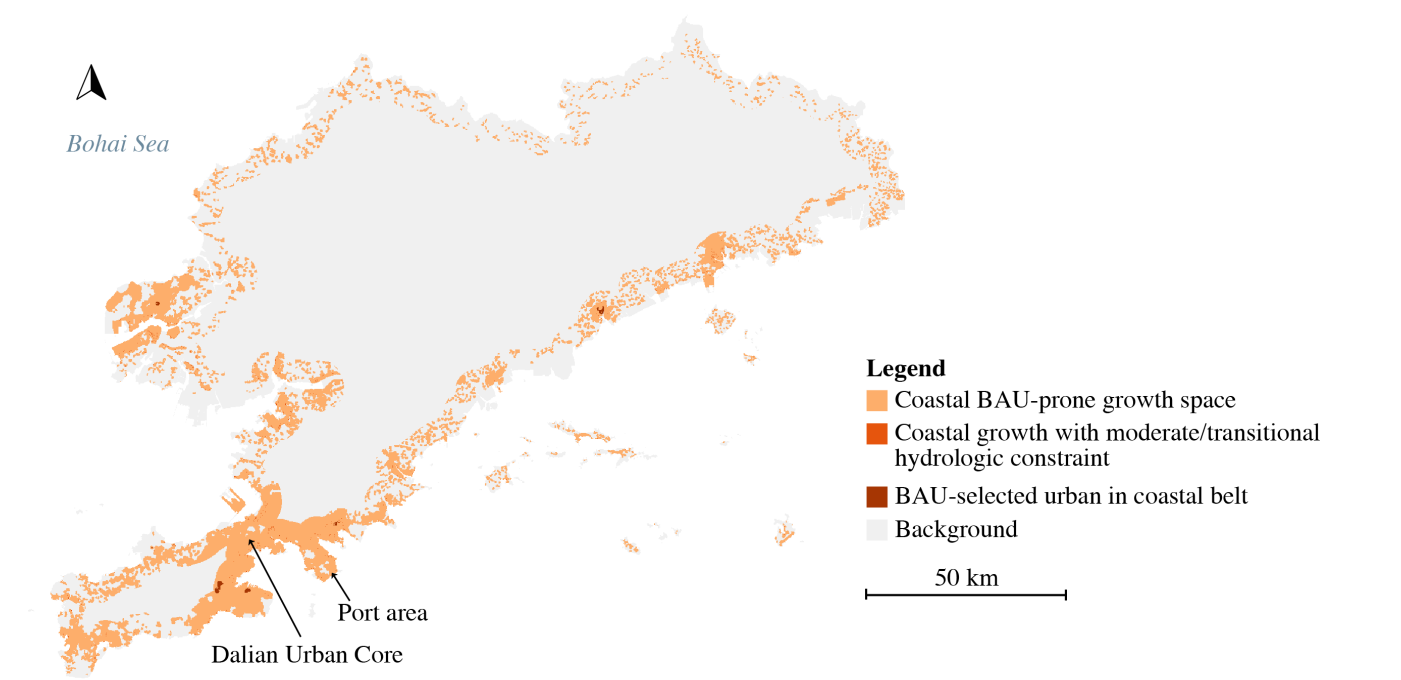


Figure 5. Growth-constraint conflict map. Four-class conflict typology for the Dalian Metropolitan Region. Background (Class 1), coastal BAU-prone growth space (Class 2), transitional-constraint coastal growth space (Class 3), and BAU-selected urban cells within the coastal belt (Class 4). Conflict concentrates along the southern port-urban coastline.

Table 4. Adaptation zoning area summary. Five zones derived from the conflict classification, planning layers, and BAU profiling results. Total study area is approximately 13,390 km².

Zone	Label	Area (km ²)	Study Area (%)	Planning Function
1	Coastal residential constraint zone	1789.32	13.36	Residential growth downweighted within coastal belt
2	Port-commercial conditional retention zone	83.35	0.62	Commercial growth conditionally retained near port anchors
3	Safer receiving area	905.91	6.77	Preferred inland destination for redirected residential growth
4	Residual coastal belt outside Zones 1–2	3221.03	24.05	Residual coastal-belt area outside targeted Zones 1–2 for monitoring and future policy
5	Background	7390.83	55.19	Remaining study area outside designated planning zones

Note: Zone areas are reported to two decimal places. Zones are mutually exclusive and sum to the full study area; each cell is assigned to a single zone. Zones 1 and 2 fall within the broader 5 km coastal belt, which totals 5093.70 km², or 38.0% of the study area. Zone 4 represents the remaining coastal-belt area after Zones 1 and 2 are excluded, and Zone 3 lies outside the belt. The relatively small areas of Zones 2 and 3 reflect their function as targeted planning instruments rather than balanced land-classification categories.

The zoning framework is a targeted planning instrument that identifies where differentiated rules matter most. The map functions less as a regulatory land use map and more as a translation device linking modeled growth dynamics to actionable planning categories (Figure 6).

Table 5 illustrates how each zone could be operationalized through candidate planning instruments. These instruments are offered as a menu for planner deliberation rather than prescriptive requirements, consistent with the screening-level status of the workflow.

Table 5. Adaptation zones and candidate planning instruments.

Zone	Label	Candidate Planning Instruments
1	Coastal residential constraint zone	Residential downzoning; stricter permitting and setback requirements; transfer of development rights (TDR) to inland receiving areas; development impact fees; removal of insurance or infrastructure subsidies; phased-retreat planning in the highest-exposure cells.
2	Port-commercial conditional retention zone	Conditional commercial retention tied to flood-proofing standards, including elevated or wet-proofed structures; port-related land-use prioritization; performance-based permitting; time-limited or reviewable approvals.
3	Safer receiving area	Upzoning and density bonuses to absorb redirected residential growth; TDR receiving designation; infrastructure investment to support inland growth capacity.
4	Residual coastal belt outside Zones 1–2	Monitoring and early-warning designation; reserved status for future adaptation policy; disclosure requirements at point of sale; trigger thresholds for escalating constraint.
5	Background	Standard land-use regulation; no coastal-specific instrument.

Note: Instruments are illustrative options for planner consideration, not prescriptive mandates; appropriate selection depends on local statutory authority, governance capacity, and stakeholder process.

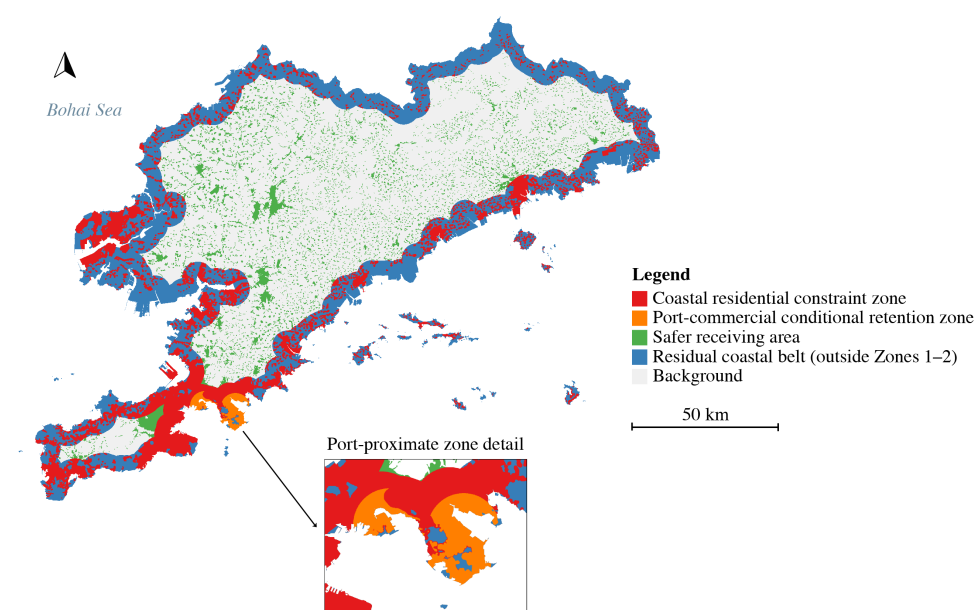


Figure 6. Adaptation zoning map. Five-zone planning typology for the Dalian Metropolitan Region. Coastal residential constraint zone (1789 km², 13.4%), port-commercial conditional retention zone (83 km², 0.6%), safer receiving area (906 km², 6.8%), residual coastal belt outside Zones 1–2 (3221 km², 24.1%), and background (7391 km², 55.2%). Zone sizes reflect targeted planning instruments rather than balanced land classification.

5. Discussion

The scenario comparison shifts the interpretation of the model outputs. Because the prior modeling framework already filters out the most hazardous land, the unresolved planning challenge in Dalian is differentiation within apparently suitable coastal space rather than exclusion from obviously exposed land. This moves the discussion from hazard recognition to spatial priority logic and frames the selective adaptation scenario as a test of how coastal growth can be redirected without changing total residential demand.

This distinction also clarifies the contribution relative to Pang and Deal [1]. In the framework paper (Pang and Deal [1]), the main question was whether integrated land use and bathtub flood-inundation modeling could identify different growth outcomes under intervention. Here, the question is different. The goal is to translate those same outputs into planning-support evidence by identifying where growth pressure overlaps with coastal constraint, how those overlaps can be classified, and which rule-based spatial responses become plausible for planners. The contribution is not a new predictive model

but a translation workflow. Its advance over reanalysis lies in the second-order planning question it addresses: how to differentiate responses among coastal cells that remain suitable for growth, rather than only identifying where growth pressure or flood exposure is concentrated. In this sense, the workflow shifts from hazard identification to pre-lock-in planning differentiation and is transferable to other contexts where calibrated allocation or hazard models exist but are not yet organized as planning evidence. Consistent with this framing, the flood-exposure layer is used as a planning-screening input rather than a definitive flood-risk assessment. The adaptation zones identify where coastal growth pressure and flood exposure converge and warrant closer hydrodynamic and site-level study, not where flood safety has been certified.

The scenario comparison makes that point more precise. Strong conservation represents a uniform restriction logic. It produces the sharpest reduction in coastal commercial allocation, but it does so by applying a broad constraint that does not distinguish among different land use functions. Selective adaptation, by contrast, demonstrates that a middle position is possible. It redirects residential growth inland while allowing partial retention of commercial activity. This is important because it shows that adaptation planning does not have to collapse into either business as usual growth or generalized restriction [44]. A differentiated scenario can produce meaningful spatial redistribution without eliminating development demand.

The residential results are especially revealing. Residential demand is fully satisfied in all scenarios, so count-based metrics alone would imply that residential rules do very little. The spatial metrics show the opposite. Under selective adaptation, residential growth moves completely outside the coastal belt and shifts substantially farther inland. This suggests that in Dalian's current allocation structure, residential control operates primarily through location rather than quantity. From a planning perspective, that is consequential. It means coastal residential exposure can be reduced not by lowering housing demand, but by changing the relative competitiveness of coastal and inland cells. More broadly, it shows why planning support evaluation cannot rely only on allocation counts. In this case, the more meaningful question is where growth goes, not simply how much growth occurs.

The sensitivity results carry a structural implication beyond their face value. Residential downweighting behaves as a threshold rather than a continuous control because non-coastal alternatives are abundant in Dalian. Belt width matters more than the magnitude of the residential down weight. The 5 km belt is used as the default because it captures the BAU coastal concentration problem, not because it represents a universal setback standard. Wider belts are tested to examine how residential redistribution responds to broader definitions of coastal management space. For planning practice, that distinction reframes belt width from an arbitrary parameter into a case-specific finding. The full sensitivity design and outputs are provided in Tables S1 and S2.

Commercial land use is more difficult to interpret and also more important quantitatively. Commercial allocation ranges from 3541 cells under BAU to 2360 under selective adaptation to 8 under strong conservation. This is expected in a port city, where some commercial space has functional coastal or port-related relevance. At the same time, the analysis intentionally treats the port-distance layer conservatively. The OSM-derived port anchors support the logic of differentiated commercial treatment, but they do not represent a complete port accessibility model. This means the commercial findings should be read as proof-of-concept rather than definitive optimization of port-related land policy. The study demonstrates that commercial land can be treated differently from residential land in a rule-based planning scenario. It does not claim that the current proxy fully captures the operational geography of Dalian's port economy.

This limitation also points to a broader contribution. The workflow distinguishes between model-derived outputs, literature-supported proxies, and study-specific operational rules. That evidence hierarchy makes the analysis more transparent and more useful for planning. It allows the study to be explicit about which layers emerge directly from the prior model, which layers are conceptual proxies introduced for planning interpretation, and which thresholds remain testable assumptions. In practice, this matters because many planning applications of spatial models fail not because the models are wrong, but because the translation from model output to decision logic remains opaque. By treating planning layers and scenario rules as explicit translation artifacts rather than hidden assumptions, the study makes that step auditable.

The adaptation zoning results illustrate this point well. The zoning map is not a balanced land classification and should not be interpreted as one. Instead, it is a targeted planning instrument that identifies where differentiated rules become relevant. The dominance of the coastal residential constraint zone and the residual coastal-belt zone reflect the underlying allocation geography of Dalian, where the main pressure is concentrated along the shoreline. The smaller extent of port commercial retention and safer receiving zones reflects their targeted role. The zoning map is less a final regulatory map than a planning support device that organizes model outputs into actionable categories.

More broadly, the study suggests a different way of thinking about smart urban planning in coastal cities. Smart planning is often associated with increasingly detailed modeling, but these results suggest that additional predictive complexity alone is not enough. What planners need is not only better forecasts, but clearer translation from modeled patterns into rule-based decisions. In this case, the most useful outputs are not the original probability or suitability surfaces by themselves, but the derived conflict classes, coastal profiling results, zoning categories, and scenario comparisons that reveal how growth might be reorganized spatially. This work shows how modeled outputs can become planning evidence rather than remaining analytical artifacts.

Limitations. Several limitations should be acknowledged. Strong conservation reuses the intervention allocation from Pang and Deal [1], so it is a reinterpretation of an existing output rather than a newly generated scenario; this is appropriate for comparing planning postures but should not be confused with a newly calibrated conservation model. The port-distance layer is used as a proof-of-concept proxy rather than a complete port-system inventory. It measures straight-line distance to OSM-identified port anchors and does not account for road or rail connectivity, travel times, terminal specialization, or throughput. Future work should incorporate port logistics indicators such as network-based accessibility, intermodal connectivity, and terminal-specific activity. The connected-bathtub flood-exposure surface is treated as an exploratory planning layer rather than a validated hydrodynamic model. It identifies low-lying, coastline-connected cells under a static water-level threshold but does not represent storm-surge propagation, wave run-up, tide surge coupling, drainage capacity, infiltration, coastal defenses, morphodynamic processes, or pluvial-coastal compound flooding. A static connected-bathtub approach maps hydraulically connected low-elevation land but not flow dynamics: it may overstate inundation where attenuation or engineered defenses limit flooding, and understate exposure where surge, wave setup, or compound rainfall-tide interactions raise water levels above the static elevation clip. The layer is built on the 30 m SRTM 1 Arc-Second DEM, whose vertical uncertainty was not formally propagated through the connected-bathtub clip; published assessments report SRTM vertical error on the order of several meters, with a positive bias in vegetated and built-up areas because radar-derived elevations represent surface rather than bare-earth terrain [45]. Because this uncertainty is comparable to the 5 m screening threshold, the suitability classes and zone boundaries should be interpreted as

screening-level planning signals rather than definitive flood-hazard determinations. Future work should replace or supplement this static surface with validated two-dimensional hydrodynamic modeling (e.g., SFINCS, MIKE 21) and higher-resolution bare-earth elevation data to refine the inland extent, spatial continuity, and dynamic behavior of coastal exposure. Finally, the adaptation zones should be interpreted as planning-support outputs rather than formally validated regulatory zones. In application, they should be compared with current master plans, urban development plans, port plans, and coastal management documents to assess consistency with existing policy priorities and planned growth areas. Stakeholder workshops with planners, port authorities, community representatives, and coastal-management agencies would help test whether the zones are institutionally feasible and locally meaningful. Such plan-based comparison and participatory validation are important next steps, but are beyond the scope of the present workflow-oriented study.

6. Conclusions

This paper reinterpreted outputs from an integrated LEAM and connected-bathtub flood-inundation study for Dalian, China, as planning layers, conflict typologies, and adaptation zones. Because the inherited flood-exposure surface is based on a static connected-bathtub approximation rather than a validated hydrodynamic model, the inundation dimension of this analysis remains exploratory; the main contribution lies in the planning-support translation workflow, which can be updated as more advanced flood-model outputs become available. The prior BAU allocation already steers growth toward lower risk spaces, so the binding planning constraint in Dalian is shoreline proximity rather than hazard exposure. Among the three scenarios compared, only selective adaptation redirected residential growth inland while retaining substantially more commercial allocation than strong conservation. Because residential demand was fully satisfied in every scenario, the meaningful effect operates through location rather than quantity.

The methodological contribution is a workflow that distinguishes model-derived layers, literature-supported proxies, and study-specific operationalizations, then tests the latter through sensitivity analysis. Limitations include reuse of the framework-paper intervention raster as the strong conservation scenario, the conservative OSM-derived port proxy, and study-specific scenario weights. The workflow shows how modeled evidence can be reorganized into spatial planning categories that planners can act on, rather than remaining as analytical artifacts.

The study offers two main implications. First, coastal planning in Dalian should be understood as a problem of differentiated management within shoreline proximate urban space, not only as a problem of keeping growth out of obviously exposed land. Second, model outputs become more useful for planners when they are reorganized into translation structures such as conflict typologies, zoning logics, and scenario rules. The paper contributes not only a case-specific planning analysis for Dalian, but also a more general demonstration of how spatial simulation outputs can be made more actionable for climate adaptation planning.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/land15071218/s1>: Table S1: Level legend used to define sensitivity response categories. Table S2: Full sensitivity-analysis parameter combinations and key outputs. Figure S1: Distance-to-coast distribution of allocated residential cells across the BAU, strong conservation, and selective adaptation scenarios.

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