SMART CONTRACT AUDIT REPORT

for

pStake stkBNB

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1 Introduction

Given the opportunity to review the design document and related smart contract source code of the `pStake` protocol on the support of `stkBNB`, we outline in the report our systematic approach to evaluate potential security issues in the smart contract implementation, expose possible semantic inconsistencies between smart contract code and design document, and provide additional suggestions or recommendations for improvement. Our results show that the given version of smart contracts can be further improved due to the presence of several issues related to either security or performance. This document outlines our audit results.

1.1 About pStake stkBNB

`pStake` is a cross-chain liquid staking solution which helps in unlocking the liquidity of the staked assets. It is designed as an inter-chain DeFi product to enable the liquid staking of PoS chains. The audited support of `stkBNB` is the `pStake`'s liquid staking implementation for `BNB`. It allows users to stake `BNB` to earn staking rewards that are auto-compounded daily to provide users with higher staking rewards. The basic information of the audited protocol is as follows:

Table 1.1: Basic Information of The stkBNB

Item	Description
Name	pStake
Website	https://persistence.one/
Type	EVM Smart Contract
Platform	Solidity
Audit Method	Whitebox
Latest Audit Report	July 4, 2022

In the following, we show the Git repository of reviewed files and the commit hash values used in this audit.

- https://github.com/persistenceOne/stkBNB-contracts.git (1333a7b)

And here is the commit ID after fixes for the issues found in the audit have been checked in:

- https://github.com/persistenceOne/stkBNB-contracts.git (8875b64)

1.2 About PeckShield

PeckShield Inc. [8] is a leading blockchain security company with the goal of elevating the security, privacy, and usability of current blockchain ecosystems by offering top-notch, industry-leading services and products (including the service of smart contract auditing). We are reachable at Telegram (https://t.me/peckshield), Twitter (http://twitter.com/peckshield), or Email (contact@peckshield.com).

Table 1.2: Vulnerability Severity Classification

Impact \ Likelihood	*High*	*Medium*	*Low*
High	Critical	High	Medium
Medium	High	Medium	Low
Low	Medium	Low	Low

1.3 Methodology

To standardize the evaluation, we define the following terminology based on OWASP Risk Rating Methodology [7]:

- Likelihood represents how likely a particular vulnerability is to be uncovered and exploited in the wild;
- Impact measures the technical loss and business damage of a successful attack;
- Severity demonstrates the overall criticality of the risk.

Likelihood and impact are categorized into three ratings: *H*, *M* and *L*, i.e., *high*, *medium* and *low* respectively. Severity is determined by likelihood and impact and can be classified into four categories accordingly, i.e., *Critical*, *High*, *Medium*, *Low* shown in Table 1.2.

To evaluate the risk, we go through a list of check items and each would be labeled with a severity category. For one check item, if our tool or analysis does not identify any issue, the

Table 1.3: The Full List of Check Items

Category	Check Item
Basic Coding Bugs	Constructor Mismatch
	Ownership Takeover
	Redundant Fallback Function
	Overflows & Underflows
	Reentrancy
	Money-Giving Bug
	Blackhole
	Unauthorized Self-Destruct
	Revert DoS
	Unchecked External Call
	Gasless Send
	Send Instead Of Transfer
	Costly Loop
	(Unsafe) Use Of Untrusted Libraries
	(Unsafe) Use Of Predictable Variables
	Transaction Ordering Dependence
	Deprecated Uses
Semantic Consistency Checks	Semantic Consistency Checks
Advanced DeFi Scrutiny	Business Logics Review
	Functionality Checks
	Authentication Management
	Access Control & Authorization
	Oracle Security
	Digital Asset Escrow
	Kill-Switch Mechanism
	Operation Trails & Event Generation
	ERC20 Idiosyncrasies Handling
	Frontend-Contract Integration
	Deployment Consistency
	Holistic Risk Management
Additional Recommendations	Avoiding Use of Variadic Byte Array
	Using Fixed Compiler Version
	Making Visibility Level Explicit
	Making Type Inference Explicit
	Adhering To Function Declaration Strictly
	Following Other Best Practices

contract is considered safe regarding the check item. For any discovered issue, we might further deploy contracts on our private testnet and run tests to confirm the findings. If necessary, we would additionally build a PoC to demonstrate the possibility of exploitation. The concrete list of check items is shown in Table 1.3.

In particular, we perform the audit according to the following procedure:

- Basic Coding Bugs: We first statically analyze given smart contracts with our proprietary static code analyzer for known coding bugs, and then manually verify (reject or confirm) all the issues found by our tool.
- Semantic Consistency Checks: We then manually check the logic of implemented smart contracts and compare with the description in the white paper.
- Advanced DeFi Scrutiny: We further review business logics, examine system operations, and place DeFi-related aspects under scrutiny to uncover possible pitfalls and/or bugs.
- Additional Recommendations: We also provide additional suggestions regarding the coding and development of smart contracts from the perspective of proven programming practices.

To better describe each issue we identified, we categorize the findings with Common Weakness Enumeration (CWE-699) [6], which is a community-developed list of software weakness types to better delineate and organize weaknesses around concepts frequently encountered in software development. Though some categories used in CWE-699 may not be relevant in smart contracts, we use the CWE categories in Table 1.4 to classify our findings.

1.4 Disclaimer

Note that this security audit is not designed to replace functional tests required before any software release, and does not give any warranties on finding all possible security issues of the given smart contract(s) or blockchain software, i.e., the evaluation result does not guarantee the nonexistence of any further findings of security issues. As one audit-based assessment cannot be considered comprehensive, we always recommend proceeding with several independent audits and a public bug bounty program to ensure the security of smart contract(s). Last but not least, this security audit should not be used as investment advice.

Table 1.4: Common Weakness Enumeration (CWE) Classifications Used in This Audit

Category	Summary
Configuration	Weaknesses in this category are typically introduced during the configuration of the software.
Data Processing Issues	Weaknesses in this category are typically found in functionality that processes data.
Numeric Errors	Weaknesses in this category are related to improper calculation or conversion of numbers.
Security Features	Weaknesses in this category are concerned with topics like authentication, access control, confidentiality, cryptography, and privilege management. (Software security is not security software.)
Time and State	Weaknesses in this category are related to the improper management of time and state in an environment that supports simultaneous or near-simultaneous computation by multiple systems, processes, or threads.
Error Conditions, Return Values, Status Codes	Weaknesses in this category include weaknesses that occur if a function does not generate the correct return/status code, or if the application does not handle all possible return/status codes that could be generated by a function.
Resource Management	Weaknesses in this category are related to improper management of system resources.
Behavioral Issues	Weaknesses in this category are related to unexpected behaviors from code that an application uses.
Business Logics	Weaknesses in this category identify some of the underlying problems that commonly allow attackers to manipulate the business logic of an application. Errors in business logic can be devastating to an entire application.
Initialization and Cleanup	Weaknesses in this category occur in behaviors that are used for initialization and breakdown.
Arguments and Parameters	Weaknesses in this category are related to improper use of arguments or parameters within function calls.
Expression Issues	Weaknesses in this category are related to incorrectly written expressions within code.
Coding Practices	Weaknesses in this category are related to coding practices that are deemed unsafe and increase the chances that an exploitable vulnerability will be present in the application. They may not directly introduce a vulnerability, but indicate the product has not been carefully developed or maintained.

2 Findings

2.1 Summary

Here is a summary of our findings after analyzing the design and implementation of the `stkBNB` feature in `pStake`. During the first phase of our audit, we study the smart contract source code and run our in-house static code analyzer through the codebase. The purpose here is to statically identify known coding bugs, and then manually verify (reject or confirm) issues reported by our tool. We further manually review business logics, examine system operations, and place DeFi-related aspects under scrutiny to uncover possible pitfalls and/or bugs.

Severity	# of Findings	
Critical	0	
High	0	
Medium	1	■
Low	1	■
Informational	1	■
Total	3	

We have so far identified a list of potential issues: some of them involve subtle corner cases that might not be previously thought of, while others refer to unusual interactions among multiple contracts. For each uncovered issue, we have therefore developed test cases for reasoning, reproduction, and/or verification. After further analysis and internal discussion, we determined a few issues of varying severities that need to be brought up and paid more attention to, which are categorized in the above table. More information can be found in the next subsection, and the detailed discussions of each of them are in Section 3.

2.2 Key Findings

Overall, these smart contracts are well-designed and engineered, though the implementation can be improved by resolving the identified issues (shown in Table 2.1), including 1 medium-severity vulnerability, 1 low-severity vulnerability, and 1 informational suggestion.

Table 2.1: Key stkBNB Audit Findings

ID	Severity	Title	Category	Status
PVE-001	Low	Suggested Sanity Checks In BasisFee::_checkValid()	Coding Practices	Confirmed
PVE-002	Informational	Meaningful Events For Important State Changes	Coding Practices	Fixed
PVE-003	Medium	Trust Issue of Admin Keys	Security Features	Mitigated

Besides recommending specific countermeasures to mitigate these issues, we also emphasize that it is always important to develop necessary risk-control mechanisms and make contingency plans, which may need to be exercised before the mainnet deployment. The risk-control mechanisms need to kick in at the very moment when the contracts are being deployed in mainnet. Please refer to Section 3 for details.

3 Detailed Results

3.1 Suggested Sanity Checks In BasisFee::_checkValid()

- ID: PVE-001
- Severity: Low
- Likelihood: Low
- Impact: Low
- Target: StakePool
- Category: Coding Practices [5]
- CWE subcategory: CWE-1126 [1]

Description

DeFi protocols typically have a number of system-wide parameters that can be dynamically configured on demand. The `pStake` protocol is no exception. Specifically, if we examine the `StakePool` contract, it has defined a number of protocol-wide risk parameters, such as `minBNBDeposit`, `minTokenWithdrawal`, `cooldownPeriod`, and `FeeDistribution`. In the following, we show the corresponding routines that allow for their changes.

```
    function updateConfig(Config.Data calldata config_) external onlyRole(
        DEFAULT_ADMIN_ROLE) {
        config._init(config_);
        emit ConfigUpdated();
    }
```

Listing 3.1: `StakePool::updateConfig()`

```
    function _init(Data storage self, Data calldata obj) internal {
        obj._checkValid();
        self._set(obj);
    }

    function _checkValid(Data calldata self) internal pure {
        self.fee._checkValid();
    }

    function _set(Data storage self, Data calldata obj) internal {
        self.bcStakingWallet = obj.bcStakingWallet;
```

```
        self.minBNBDeposit = obj.minBNBDeposit;
        self.minTokenWithdrawal = obj.minTokenWithdrawal;
        self.cooldownPeriod = obj.cooldownPeriod;
        self.fee._set(obj.fee);
    }
```

Listing 3.2: `Config::_init()/_checkValid()/_set()`

```
    function _checkValid(Data calldata self) internal pure {
        self.reward._checkValid();
        self.deposit._checkValid();
        self.withdraw._checkValid();
    }

    function _set(Data storage self, Data calldata obj) internal {
        self.reward = obj.reward;
        self.deposit = obj.deposit;
        self.withdraw = obj.withdraw;
    }
```

Listing 3.3: `FeeDistribution::_checkValid()/_set()`

```
    function _checkValid(uint256 self) internal pure {
        if (self > _BASIS) {
            revert NumeratorMoreThanBasis();
        }
    }
```

Listing 3.4: `BasisFee::_checkValid()`

These parameters define various aspects of the protocol operation and maintenance and need to exercise extra care when configuring or updating them. Our analysis shows the update logic on these parameters can be improved by applying more rigorous sanity checks. Based on the current implementation, certain corner cases may lead to an undesirable consequence. For example, an unlikely mis-configuration of `minTokenWithdrawal` may cause users to be unable to withdraw their staked assets from the `StakePool`.

Recommendation Validate any changes regarding these system-wide parameters to ensure they fall in an appropriate range.

Status This issue has been confirmed.

3.2 Meaningful Events For Important State Changes

- ID: PVE-002
- Severity: Informational
- Likelihood: N/A
- Impact: N/A
- Target: StakePool
- Category: Coding Practices [5]
- CWE subcategory: CWE-563 [3]

Description

In Ethereum, the event is an indispensable part of a contract and is mainly used to record a variety of runtime dynamics. In particular, when an event is emitted, it stores the arguments passed in transaction logs and these logs are made accessible to external analytics and reporting tools. Events can be emitted in a number of scenarios. One particular case is when system-wide parameters or settings are being changed. Another case is when tokens are being minted, transferred, or burned.

In the following, we use the StakePool contract as an example. While examining the events that reflect the StakePool dynamics, we notice there is a lack of emitting related event to reflect important state change. Specifically, when the initiateDelegation()/unbondingInitiated()/unbondingFinished() are being called, there are no corresponding events being emitted to reflect the occurrence of initiateDelegation()/unbondingInitiated()/unbondingFinished().

```
    function initiateDelegation() external whenNotPaused onlyRole(BOT_ROLE) returns (
        uint256) {
        uint256 miniRelayFee = _TOKEN_HUB.getMiniRelayFee();
        uint256 stakableBNB = getStakableBNB();

        if (stakableBNB > 0) {
            // TODO: should we charge the relay fee from the bot?
            _TOKEN_HUB.transferOut{ value: stakableBNB + miniRelayFee }(
                _ZERO_ADDR,
                config.bcStakingWallet,
                stakableBNB,
                uint64(block.timestamp + 3600)
            );
        }

        return stakableBNB;
    }
```

Listing 3.5: StakePool::initiateDelegation()

```
    function unbondingInitiated(uint256 _bnbUnbonding) external whenNotPaused onlyRole(
        BOT_ROLE) {
        bnbToUnbond -= _bnbUnbonding;
        bnbUnbonding += _bnbUnbonding;
```

```
    }
```

Listing 3.6: `StakePool::unbondingFinished()`

```
    function unbondingFinished() external whenNotPaused onlyRole(BOT_ROLE) {
        uint256 unbondedAmount = IUndelegationHolder(payable(addressStore.
            getUndelegationHolder()))
            .withdrawUnbondedBNB();
        bnbUnbonding -= unbondedAmount;
        claimReserve += unbondedAmount;
    }
```

Listing 3.7: `StakePool::unbondingFinished()`

Recommendation Properly emit the related events when the above-mentioned functions are being invoked.

Status The issue has been fixed by this commit: `8875b64`.

3.3 Trust Issue of Admin Keys

- ID: PVE-003
- Severity: Medium
- Likelihood: Medium
- Impact: Medium
- Target: `Multiple contracts`
- Category: Security Features [4]
- CWE subcategory: CWE-287 [2]

Description

In `stkBNB`, there are two privileged accounts, i.e., `owner`, and `DEFAULT_ADMIN_ROLE`. These accounts play a critical role in governing and regulating the system-wide operations (e.g., set key parameters for the `AddressStore` contract, pause/unpause the `StakePool/StakedBNBToken` contract, self-destruct the `StakedBNBToken` contract, add more `MINTER_ROLE/BURNER_ROLE` for the `StakedBNBToken` contract, add more `BOT_ROLE` for the `StakePool` contract, etc.). Our analysis shows that these privileged accounts need to be scrutinized. In the following, we use the `StakePool` contract as an example and show the representative functions potentially affected by the privileges of the `DEFAULT_ADMIN_ROLE` account.

```
    /**
     * @dev pause: Used by admin to pause the contract.
     *             Supposed to be used in case of a prod disaster.
     *
     * Requirements:
     *
     * - The caller must have the DEFAULT_ADMIN_ROLE.
     */
    function pause() external onlyRole(DEFAULT_ADMIN_ROLE) whenNotPaused {
```

```
        _paused = true;
        emit Paused(msg.sender);
    }

    /**
     * @dev unpause: Used by admin to resume the contract.
     *                Supposed to be used after the prod disaster has been mitigated
        successfully.
     *
     * Requirements:
     *
     * - The caller must have the DEFAULT_ADMIN_ROLE.
     */
    function unpause() external onlyRole(DEFAULT_ADMIN_ROLE) whenPaused {
        _paused = false;
        emit Unpaused(msg.sender);
    }

    /**
    * @dev updateConfig: Used by admin to set/update the contract configuration.
    *                    It is allowed to update config even when the contract is paused
        .
    *
    * Requirements:
    *
    * - The caller must have the DEFAULT_ADMIN_ROLE.
    */
   function updateConfig(Config.Data calldata config_) external onlyRole(
       DEFAULT_ADMIN_ROLE) {
       config._init(config_);
       emit ConfigUpdated();
   }
```

Listing 3.8: Example Privileged Operations in `StakePool`

We understand the need of the privileged functions for contract maintenance, but at the same time the extra power to the owner may also be a counter-party risk to the protocol users. It is worrisome if the privileged `DEFAULT_ADMIN_ROLE` account is a plain EOA account. Note that a multi-sig account could greatly alleviate this concern, though it is still far from perfect. Specifically, a better approach is to eliminate the administration key concern by transferring the role to a community-governed DAO.

Recommendation Promptly transfer the privileged account to the intended `DAO`-like governance contract. All changes to privileged operations may need to be mediated with necessary timelocks. Eventually, activate the normal on-chain community-based governance life-cycle and ensure the intended trustless nature and high-quality distributed governance.

Status This issue has been mitigated as the team confirms that multi-sig will be adopted for the privileged `owner/admin` accounts.

4 Conclusion

In this audit, we have analyzed the design and implementation of the pStake protocol on the support of stkBNB. The audited support of stkBNB is pSTAKE's liquid staking implementation for BNB which allows users to stake any non-zero amount of BNB to earn staking rewards that are auto-compounded daily to provide users with higher staking rewards while allowing them to use stkBNB in the broader BNB chain ecosystem to participate in DeFi. The current code base is well structured and neatly organized. Those identified issues are promptly confirmed and addressed.

Meanwhile, we need to emphasize that Solidity-based smart contracts as a whole are still in an early, but exciting stage of development. To improve this report, we greatly appreciate any constructive feedbacks or suggestions, on our methodology, audit findings, or potential gaps in scope/coverage.

References

[1] MITRE. CWE-1126: Declaration of Variable with Unnecessarily Wide Scope. https://cwe.mitre.org/data/definitions/1126.html.

[2] MITRE. CWE-287: Improper Authentication. https://cwe.mitre.org/data/definitions/287.html.

[3] MITRE. CWE-563: Assignment to Variable without Use. https://cwe.mitre.org/data/definitions/563.html.

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[5] MITRE. CWE CATEGORY: Bad Coding Practices. https://cwe.mitre.org/data/definitions/1006.html.

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[7] OWASP. Risk Rating Methodology. https://www.owasp.org/index.php/OWASP_Risk_Rating_Methodology.

[8] PeckShield. PeckShield Inc. https://www.peckshield.com.